STATE OF FLORIDA
DEPARTMENT OF NATURAL RESOURCES
Harmon Shields, *Executive Director*

DIVISION OF INTERIOR RESOURCES
R. O. Vernon, *Director*

BUREAU OF GEOLOGY
C. W. Hendry, Jr., *Chief*

SPECIAL PUBLICATION NO. 20

GEOLOGIC FRAMEWORK OF THE HIGH TRANSMISSIVITY ZONES IN SOUTH FLORIDA

By
Harbans S. Puri and George O. Winston

Prepared by the
BUREAU OF GEOLOGY
DIVISION OF INTERIOR RESOURCES
in cooperation with
UNITED STATES GEOLOGICAL SURVEY

TALLAHASSEE
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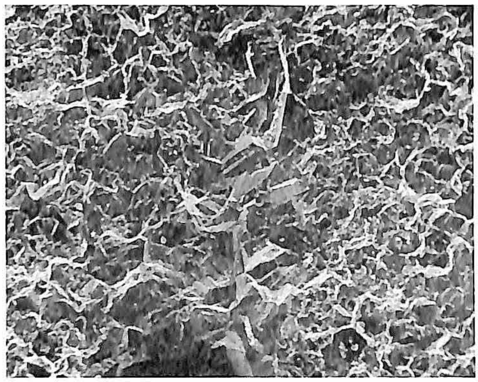

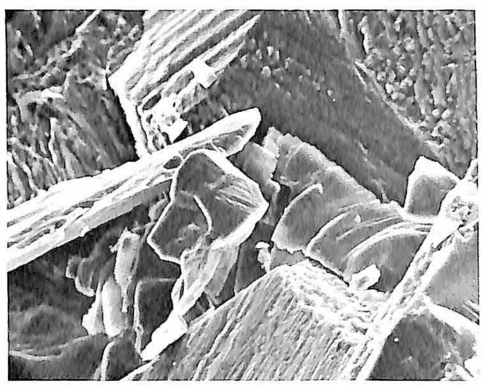

LETTER OF TRANSMITTAL

Bureau of Geology
Tallahassee
February 15, 1974

Honorable Reubin O'D. Askew, *Chairman*
Department of Natural Resources
Tallahassee, Florida

Dear Governor Askew:

The Bureau of Geology is publishing as its Special Publication No. 20 a report entitled, "Geologic Framework of the High Transmissivity Zones of South Florida", prepared by Dr. Harbans S. Puri and George O. Winston. We believe this report, along with two others to follow, will provide valuable information concerning the potential for deep subsurface waste storage in Florida.

In 1969, the Secretary of Interior charged the U. S. Geological Survey with the responsibility fo conducting a research program to evaluate the "effects of underground waste disposal on the Nation's subsurface environment, with particular attention to ground water." As a part of this charge, the U. S. Geological Survey began investigating the hydrologic and geochemical aspects of subsurface waste storage in Florida. In addition, through a grant (Grant No. 14-08-0001-G36) from the nationwide research program of the U. S. Geological Survey, the Bureau of Geology, Florida Department of Natural Resources is investigating the geologic aspects of subsurface waste storage in Florida. This paper represents work accomplished in the South Florida area in satisfaction of the grant instrument.

Sincerely yours,

C. W. Hendry, Jr., *Chief*
Bureau of Geology

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ACKNOWLEDGEMENTS

We wish to acknowledge the support of the U. S. Geological Survey, who, under a directive from the Secretary of the Interior to evaluate the effects of subsurface waste disposal in the United States, have provided financial support for this study under U. S. Geological Survey Grant No. 14-08-0001-G36.

Several persons and organizations have contributed to this study of the high transmissivity zone. We wish to express our appreciation to the Sun Oil Company for providing photographs from their photo survey of the zone and for permission to publish these in this study, and to the Exxon Company for collecting and providing drilling-time data on many wells in this area. We have benefited from discussions with colleagues, particularly J. E. Banks and E. J. Henderson, for their first-hand experiences in drilling through the cavernous zones on drilling problems encountered by the industry.

Dr. R. O. Vernon, Director, Division of Interior Resources, who has done much initial work on this zone, and C. W. Hendry, Jr., Chief, Bureau of Geology, contributed advice and encouragement.

Francis A. Kohout, Mathew I. Kaufman and Glen L. Faulkner, U. S. Geological Survey, were most helpful in presenting the geohydrological problems involved in this study.

GEOLOGIC FRAMEWORK OF THE HIGH TRANSMISSIVITY ZONES IN SOUTH FLORIDA

By
Harbans S. Puri and George O. Winston

INTRODUCTION

Streams and rivers have been the perennial dumping grounds for industrial and human wastes. The passage of the Federal Clean Streams Act of 1966, and the stricter reinforcement of pollution control laws already on the books, have discouraged the discharge of industrial and municipal wastes into surface waters. Consequently, a demand has arisen for methods in which industrial and human wastes can safely be discharged into the subsurface. The deep saline part of the Floridan aquifer has been, for years, used by the oil industry for the injection of oil-field brines. Deep injection wells for industrial waste disposal are currently also using the lower saline part of the Floridan aquifer. There are indications of an increasing necessity to use the deep, high-salinity part of the aquifer for subsurface liquid-waste injection and to use the brackish-fresh water part for fresh water storage (see Vernon, 1970, p. 33).

The Floridan aquifer underlies the entire State of Florida and adjoining parts of Georgia, Alabama, and South Carolina. The upper fresh water part of the aquifer is the source of drinking water for thousands of municipalities and irrigation systems. The Floridan aquifer is over 2,000 feet thick and consists of "very" porous and permeable limestones or dolostones with widely varying porosities and permeabilities. Under the force of gravity, relatively fresh water in the upper part of the aquifer flows seaward. In the Kendall sewage disposal well (No. 48) between 1800 and 1900 feet, the salinity increased nearly 3 fold from 6400 to 17,600 mg/l chlorides. One thousand feet deeper, at 2947 feet total depth, the salinity had risen to 19,300 mg/l, the concentration of sea water. Data to establish the direction and extent of the flow in the salt-water part of the aquifer (from 1000 feet to 3,000 feet below mean sea level) are not available at this time.

Industrially, it is important to understand the hydrologic and geologic factors which control horizontal and vertical fluid movements in the aquifer in order to be able to predict the ultimate direction of migration and rate of flow of the liquid wastes which may be injected into the system.

In 1969, the Secretary of Interior charged the U. S. Geological Survey with the responsibility of conducting a research program to evaluate the "effects of underground waste disposal on the Nation's subsurface environment, with particular attention to ground water." As a part of this charge, the U. S.

Geological Survey began investigating the hydrologic and geochemical aspects of subsurface waste storage in Florida. In addition, through a grant (Grant No. 14-08-0001-G36) from the nationwide research program of the U.S. Geological Survey, the Bureau of Geology, Florida Department of Natural Resources is investigating the geologic aspects of subsurface waste storage in Florida. This paper represents work accomplished in the South Florida area in satisfaction of the grant instrument.

PURPOSE

The purpose of this study is to provide answers to the nature of the geologic framework which constitutes the environment of a potential waste-storage system in South Florida. The research was undertaken to provide data for or to aid in the study of the following problems:

a. Delineation of lost circulation zones as potential waste-disposal and fresh water storage zones, and the determination of thickness, spatial distribution and number of zones of high transmissivity.
b. The lithologic nature and lateral extent of the confining beds and their capability of confining wastes to the injection horizon.
c. Direction and patterns of movements of fluids within the waste-disposal zones under natural conditions.
d. Possible interactions between liquid wastes and the enclosing rock or fluids in the injection zones, and thereby forecasting the ultimate disposal of the liquid wastes.
e. Provide field data for use in the development of theoretical and lab models of the aquifer.
f. Establish whether the cavity system containing saline water in South Florida is a part of the same hydrologic regime as the cavities developed in the fresh-water aquifer in the northern part of the peninsula.

The following geologic research in fulfillment of the objectives outlined above was conducted:

1. The high transmissivity zones in South Florida were defined, delineated, and mapped.
2. The dense zones between the lower and upper parts of the Floridan aquifer were defined, delineated, and mapped.
3. The geologic horizon, especially at the top and bottom of the zones of high transmissivity, were established through a study of rock cuttings and cores.

METHODS

To understand the origin and distribution of the cavities, it is necessary to understand the geologic setting in which they are found. As the major portion of the high transmissivity zone is concentrated in the Eocene, an intensive study of the geology of this system was undertaken. The narrow belt of high transmissibty in the Paleocene and Upper Cretaceaous contained little stratigraphic data, therefore, only an incomplete study of this section could be made.

The pattern of exploration drilling in south Florida and the general lack of returns from the lower Eocene resulted in the widely spaced control grid seen on the facies maps. A survey of all oil tests was made for availability of samples in the Eocene. Wells with the most complete set of samples (see Fig. 1) were selected for examination. Of great value was the U. S. Gypsum Company mineral test well in Collier County (Well 30) which cored much of the Eocene section.

Electric log tops were correlated with sample data when possible. As the top of the Eocene is almost always behind casing, and therefore not logged, paleontologic tops were used in mapping Eocene thickness and structure.

Sun Oil Company's set of stereo photos of the Eocene from a well in south Florida was the basis for describing the character of the voids. Drilling time logs and notations of the driller were vital for accurate figures on placement and thickness of cavities and caverns.

The personal observations of geologists in the oil industry who witnessed the drilling of cavernous zones were also valuable in making proper geological interpretation.

PREVIOUS STUDIES

Studies on solution and zones of high transmissivity have been published by Vernon (1947, 1951, 1970), and Garcia-Bengochea and Vernon (1967), Puri and Banks (1959), Chen (1965), Hanshaw (1965, 1970), Kohout (1965, 1967), Henry and Kohout (1972) and Henry and Hilleke (1972).

Kohout (1965) used the name "Boulder Zone" for the saline part of the Floridan aquifer. The term "Boulder Zone" is misleading as no true boulders are present. However, the term has been used for decades for this zone because the drilling action during penetration was as if the zone consisted of boulders. This interval represents a highly porous zone of vug and occasionally cavern-size openings and is referred to in this paper as the zone of high transmissivities or as cavity zones.

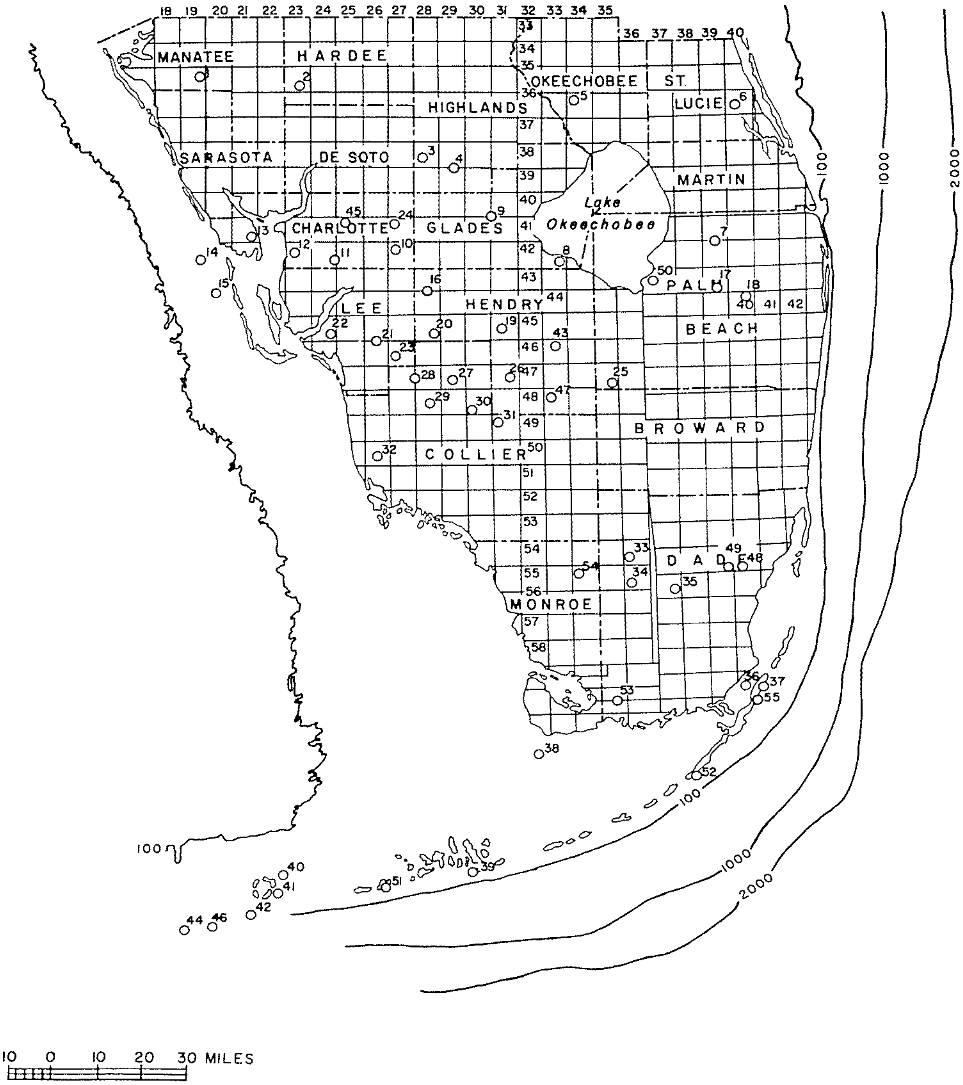


Figure 1 Map showing location of wells studied (listed in Appendix 3)

There are two hypotheses on the circulation pattern in the cavernous zone. These include temperature anomalies and hydrologic heads, with accompanying geochemical changes that occur along the interface of water bodies that differ in soluable salts to account for the dolomite. Temperature anomalies in oil wells led Kohout (1965, 1967) to postulate that cold seawater in the Gulf of Mexico and the Florida Straits flows inland into the deep saline part of the Floridan aquifer through the very permeable dolostones. A convection pattern is postulated by Kohout, where dense, cold, sea water would rise as it was progressively warmed by geothermal heating. It then mixes with the fresh-water of the upper Florida aquifer and discharges back into the Gulf of Mexico and the Straits of Florida. Henry and Kohout (1972) and Henry and Hilleke (1972) offer supporting evidence based on the simulation of actual field conditions by a computer model.

Vernon (1947, 1951, 1970) believed that geohydrologic heads, resulting in part from sea-level fluctuations, created porous and impervious beds by the dissolution and precipitation of limestone, dolostone, and gypsum. The direction of water flow was established in response to hydrologic heads existing at various levels in various geologic periods (Vernon, 1970).

The present study indicates that several distinct zones of high and low transmissivity are present in the Floridan aquifer, and that the entire Floridan aquifer in South Florida may not act as one hydrologic unit. Field data measurements are needed to establish definite directions and rates of circulation in the Floridan aquifer.

STRUCTURE

Major geologic structures in South Florida are superimposed on the bathymetric map of the Gulf-Caribbean-Antillean region as shown on Figure 2. Most of the features appear on structure contour maps of the top of the Cretaceous (Fig. 3) and of the Paleocene Cedar Keys C bed, the highest bed on which the writers believe that a valid regional structure map can be made. This latter bed apparently was not affected by solution, collapse, or erosion, as were parts of the overlying Eocene.

On this map the southerly dip of approximately 15 feet per mile changes below the 3600 foot contour into a large, essentially flat trough that extends throughout most of Hendry, Lee, and Collier counties. Lack of control precludes an accurate determination of the structure in the Broward County area.

South of the north branch of the Broward Trough, the Forty Mile Bend High and the Largo High are prominent. The most distinctive negative feature is the center of the Basin off the modern southwest coast.

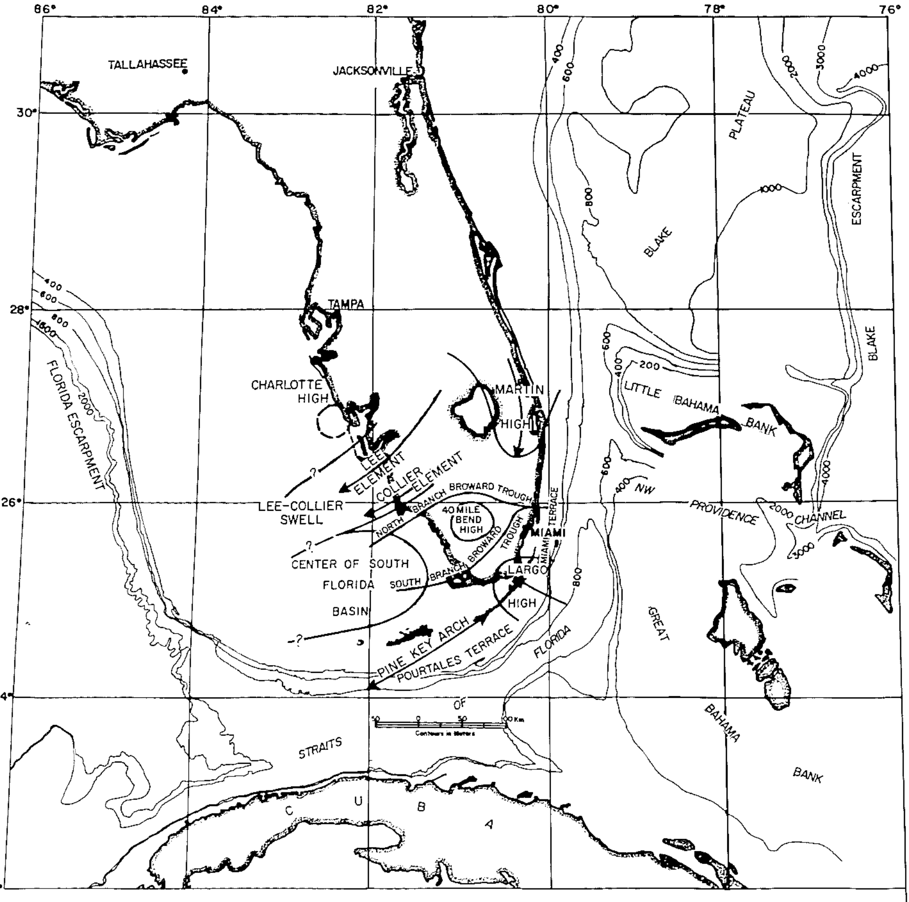


Figure 2 **Bathymetric map of Gulf - Carribean - Antillean Region with onshore and offshore structural features.**

The structure and mode of formation of the northern Florida Straits, the eastern margin of the Eocene sedimentary province, is still a matter of controversy, but the features seem to have appeared in Late Upper Cretaceous or Early Palocene time, probably by faulting.

GEOLOGIC HISTORY

The South Florida Basin, a segment of the Florida-Bahama Platform, has been an area of slow subsidence since at least Upper Jurassic time. During this time, the environment of the South Florida Basin has been essentially that of a shallow to deep shelf supporting carbonate and evaporitic cyclic deposition (Winston, 1972). During the Jurassic and Lower Cretaceous, the Platform

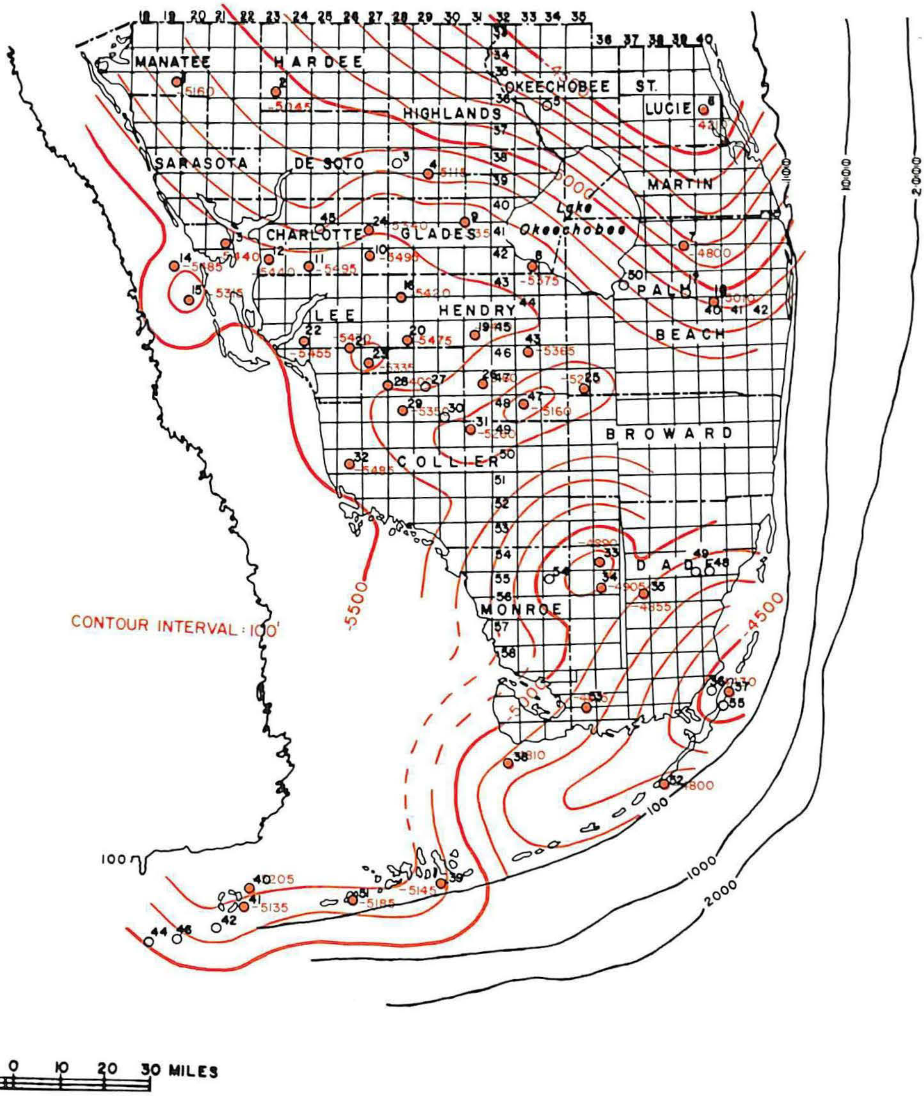


Figure 3 Structure contour map drawn on the top of the Upper Cretaceous.

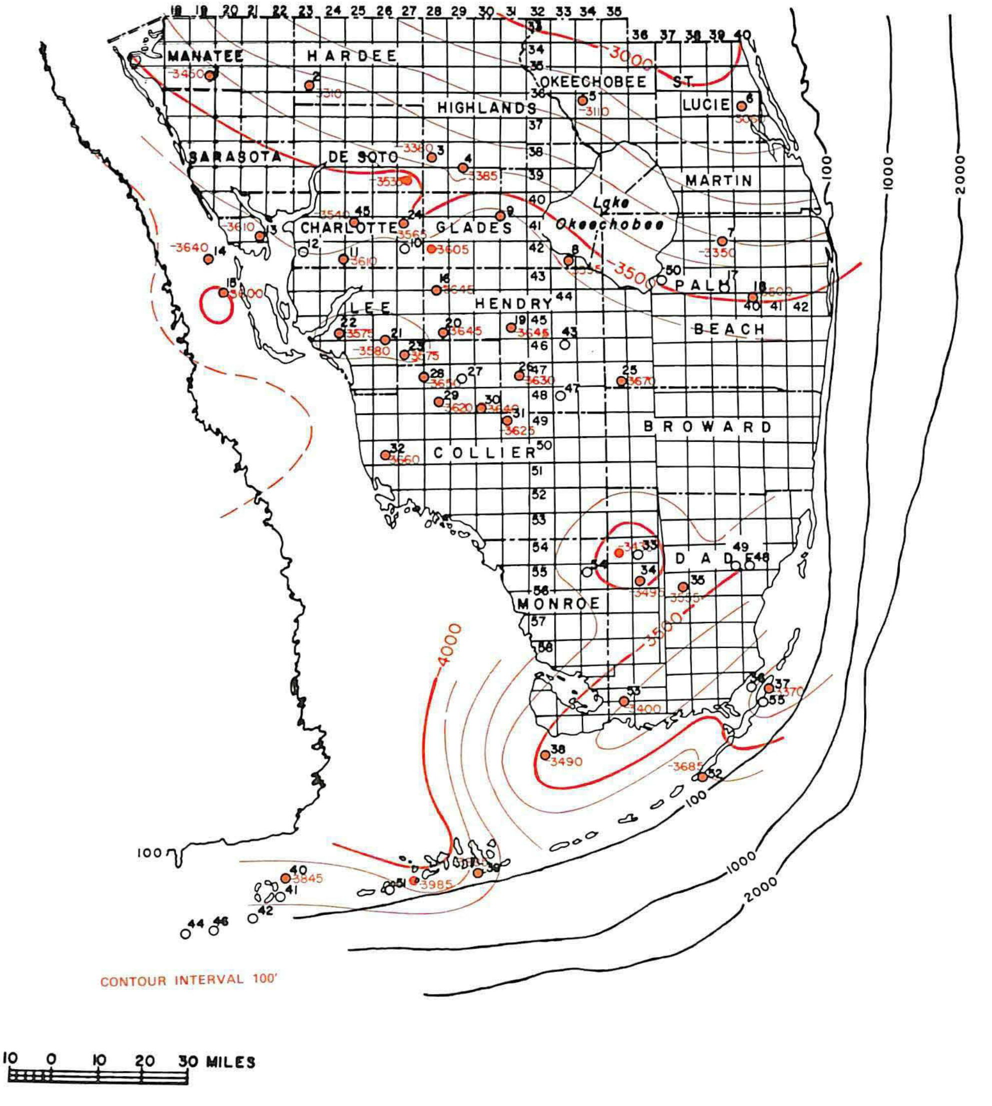


Figure 4. Structure contour map drawn on the top of the Cedar Keys C Electric-log marker.

extended from the Florida Escarpment in the west, eastward to the Blake-Bahama Escarpment and from Southern Georgia into the northern part of Cuba (Fig. 2) and was bounded by a barrier reef (Bryant et. al. 1969). In Upper Cretaceous time, however, this pattern changed, resulting in the deposition of a new lithologic sequence dominated by chalk.

During the Upper Cretaceous, major tectonic activity commenced in Cuba, during which the southern Florida Straits were probably formed, thus limiting the once broad South Florida Basin to the area north of the Pine Key Arch (Fig. 2). The southern margin of the Straits is highly faulted near Cuba. The northern margin of the Straits lies south of the Keys and less intensive faulting is indicated here by the development of the Pourtales and Miami Terraces. The Northern Straits did not come into existence until latest Upper Cretaceous or Paleocene.

Following the formation of the Northern Straits a narrow Upper Cretaceous bank system, possibly behind a windward reef, developed in the vicinity of the present edge of the Continental Shelf and the modern east coast of Florida. Deposition of bank-type carbonate sediments continued through much of Paleocene time. The presence of Paleocene evaporites suggests that a reef may have extended completely around the edge of the Continental Shelf, thus restricting sea water interchange.

In Eocene time, the barrier reef, as shown on a marine seismic profile off Miami (Fig. 5 and 6) was probably discontinuous, as evaporite deposition in the Eocene is very limited. The presence of a high energy environment near the modern southeast coast is indicated by the presence of thick, clean, grainstones.

The deposition of numerous peat and/or lignite beds indicates that parts of the sea floor were exposed during the Eocene. It would appear from our study that these minor Eocene unconformities are related to the formation of the Eocene cavities.

Following deposition of the Eocene, a large unconformity developed which when mapped in detail (see Vernon, 1951) shows relief of as much as 200 feet. Karst topography, however is very local in extent, (see Fig. 5), and appears only on detailed mapping. It consists of an occasional sinkhole.

In Oligocene, Miocene, Pliocene, and Pleistocene times, the South Florida Basin for practical purposes had ceased to exist. Several major and minor unconformities with corresponding transgression and regression of the sea occur during this interval. The complex carbonate-clastic facies relationships within this section are not yet fully understood.

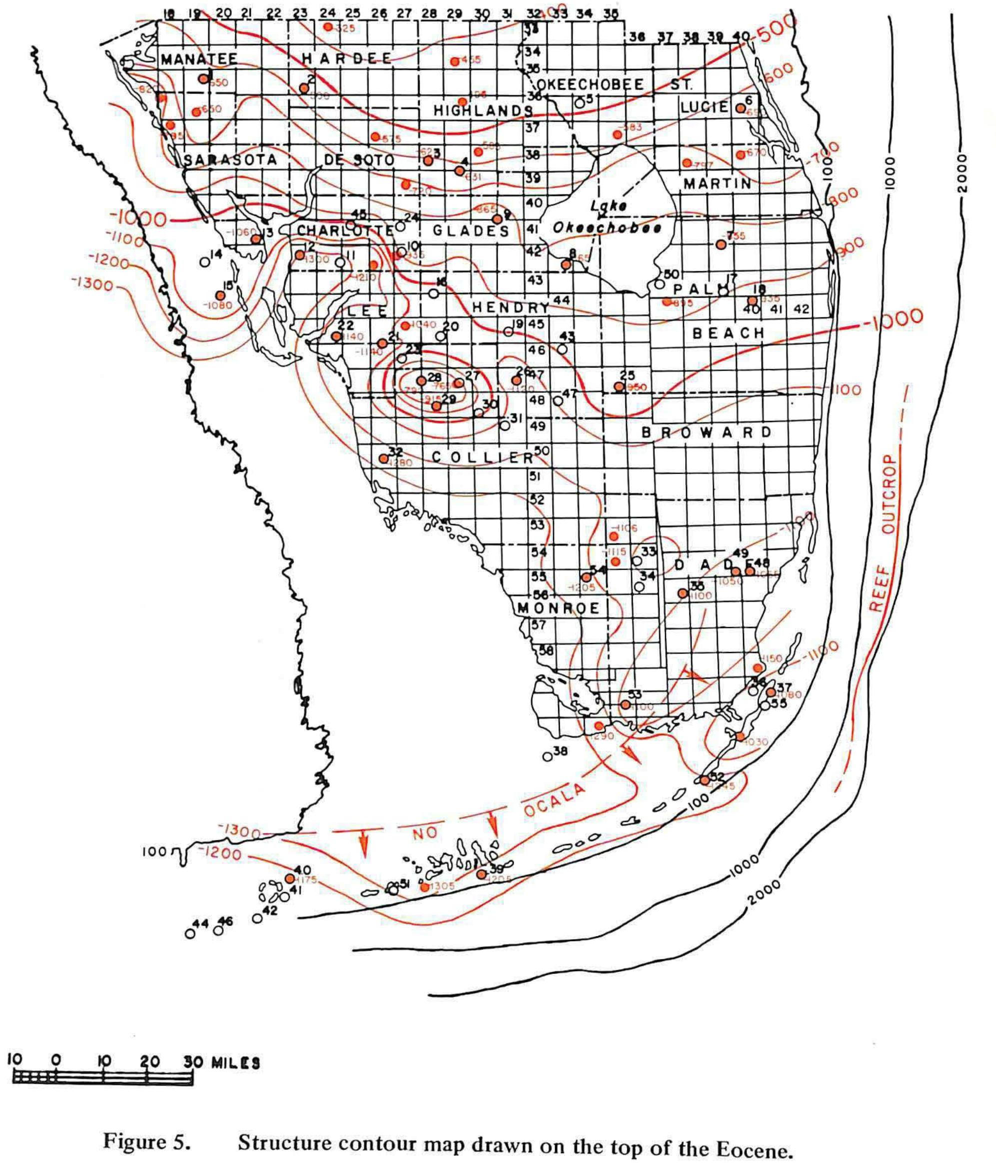


Figure 5. Structure contour map drawn on the top of the Eocene.

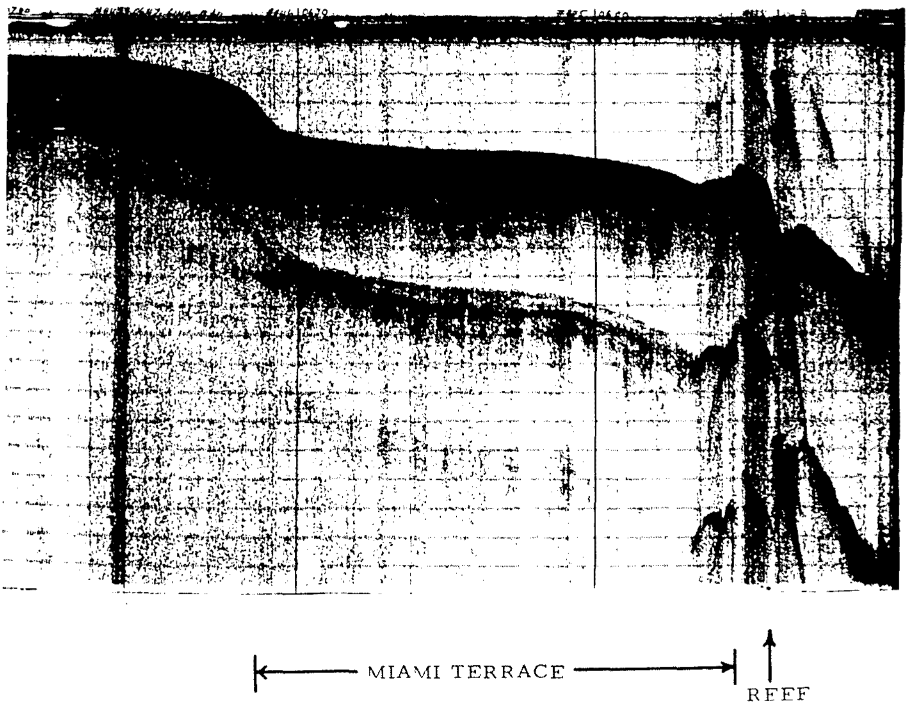


Figure 6 **Marine seismic 3000 joule arcer profile 444 (published as profile XI, Malloy and Hurley, 1970) off Miami, Florida showing the Miami Terrace and a Tertiary (Eocene) reef.**

STRATIGRAPHY

GENERAL

Areally, most of the zones of high transmissivity are confined to the Eocene, therefore, this section was studied more intensively than were the Cedar Keys and Upper Cretaceous cavity zones which occur only in a narrow belt along the east coast of Florida, as is discussed later in the report.

PRE - EOCENE

UPPER CRETACEOUS: PINE KEY GROUP

In the South Florida Basin, the Pine Key Group (Meyerhoff, 1973) is composed almost entirely of chalk, either limestone or dolostone. Along the Keys and in St. Lucie County, massive, brown, fine to medium anhedral crystalline, shallow bank-type dolostones appear in the upper portion of the Group (see Figs 7 and 8). As these parallel the present location of the Florida Straits, their origins are probably related.

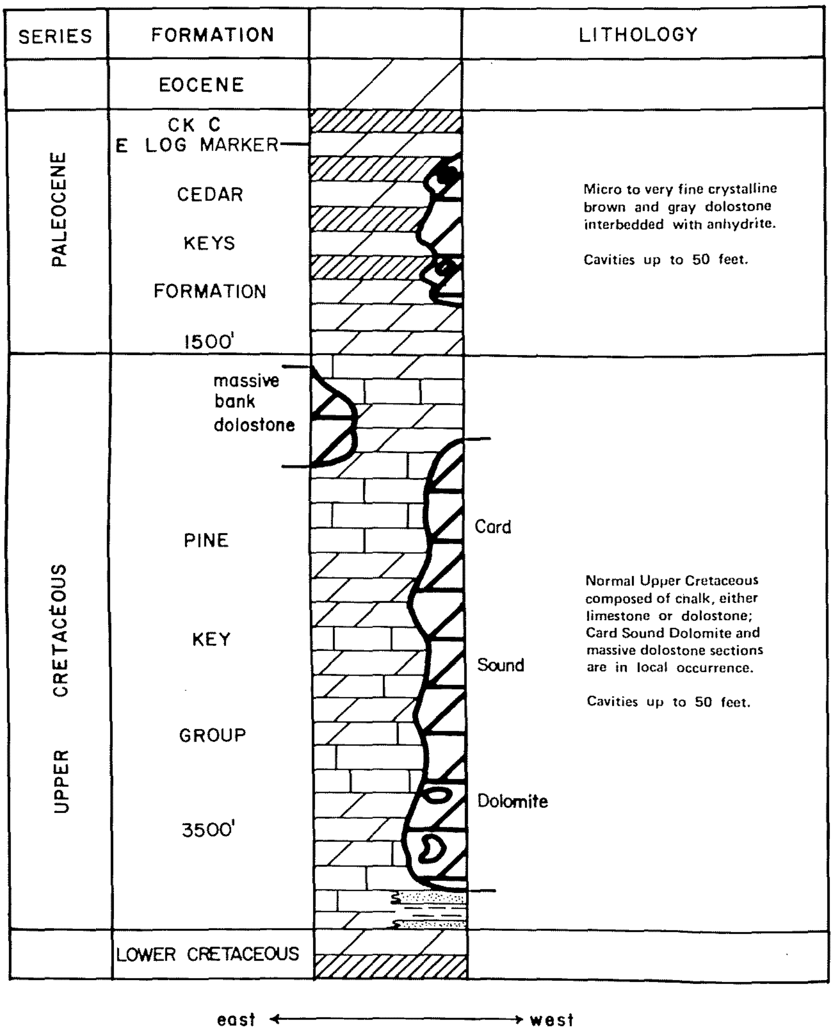


Figure 7 **Generalized geologic column for the Upper Cretaceous and the Paleocene rocks in South Florida.**

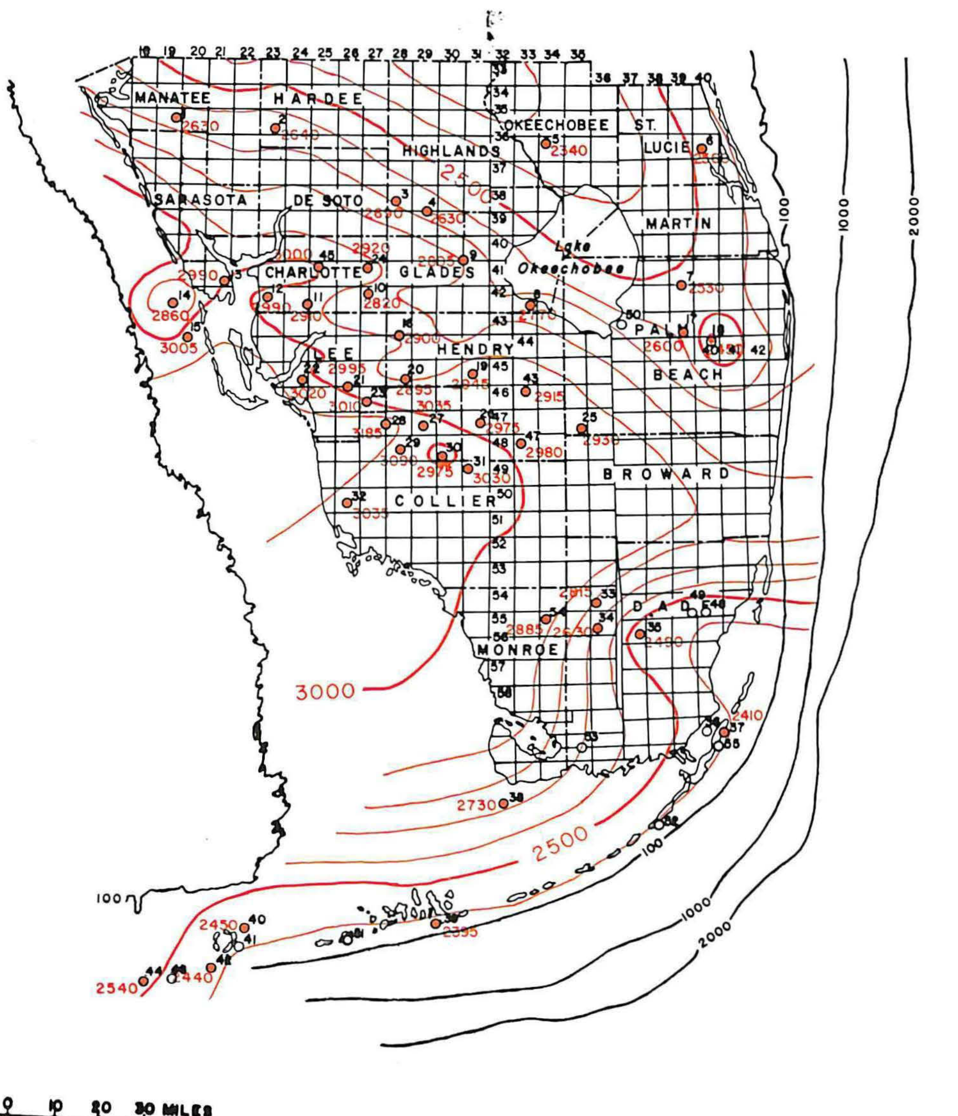


Figure 8 Isopach map of the Upper Cretaceous.

PALEOCENE: CEDAR KEYS FORMATION

The Cedar Keys Formation overlies the Upper Cretaceous conformably and underlies the Eocene conformably. Regionally it is composed of dolostones and anhydrite. The dolostone is usually gray or brown, crystalline, euhedral, and is frequently evaporitic in origin. Dolomite crystal size is usually fine to very fine, but occasionally fine crystalline and sucrosic textures were observed. The top of the Cedar Keys' thick anhydrite section usually occurs about 200 feet below the top of the formation, but anhydrite occasionally may be present at the contact. In some wells, the Cedar Keys dolostone immediately below the Eocene is a dolomitized version of the grainstone skeletal limestones of the Eocene. This, coupled with the occasional presence of anhydrite and evaporitic dolostone in the lower part of the Eocene, suggests regional interfingering of lithologies at the Eocene-Cedar Keys boundary; therefore, for mapping and study purposes, the top of Cedar Key C marker (see Figs. 4, 7, 9) was used.

EOCENE

As there are no reliable regional markers in this Series, it was subdivided for mapping purposes into three equal (Fig. 10) parts, Eo-1, Eo-2, and Eo-3.

LITHOLOGY

LIMESTONE

The lithology of the Eocene beds, their thickness and occurrence of cavities is summarized in Figure 10. Several Eocene limestone textural types are combined into a sedimentary cycle (Fig. 11), which is usually more complete in Eo-1 than in Eo-2 or Eo-3.

Within the Eocene section, two textures of limestone predominate. Skeletal grainstone with 80-100% very fine to medium grains (Bed 4, Fig. 11) is usually tan, or cream. Foraminifera are common. Cementation is weak, frequently permitting the grains to be disassociated by drilling. Only very small amounts of micrite or cement are present.

The other type, a skeletal packstone, contains only 50-70% very fine broken skeletal grains and much chalky micritic interstitial material (Bed 3, Fig. 11). Color is predominately cream, but tan and white are occasionally seen. Foraminifera are not common.

Chalky or dense micrite are infrequently encountered.
Dark colors in Eocene limestone are conspicuously absent.

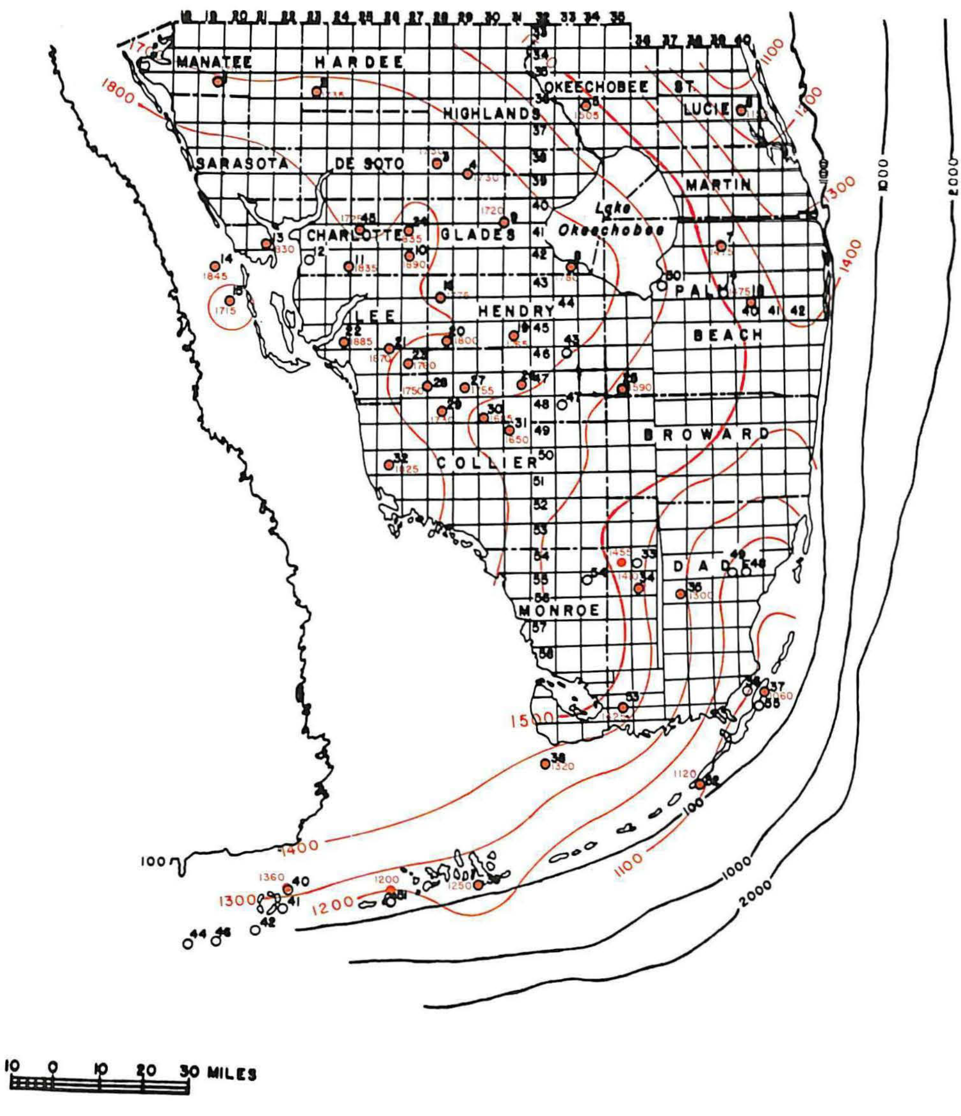


Figure 9 Isopach map of the Cedar Keys Formation.

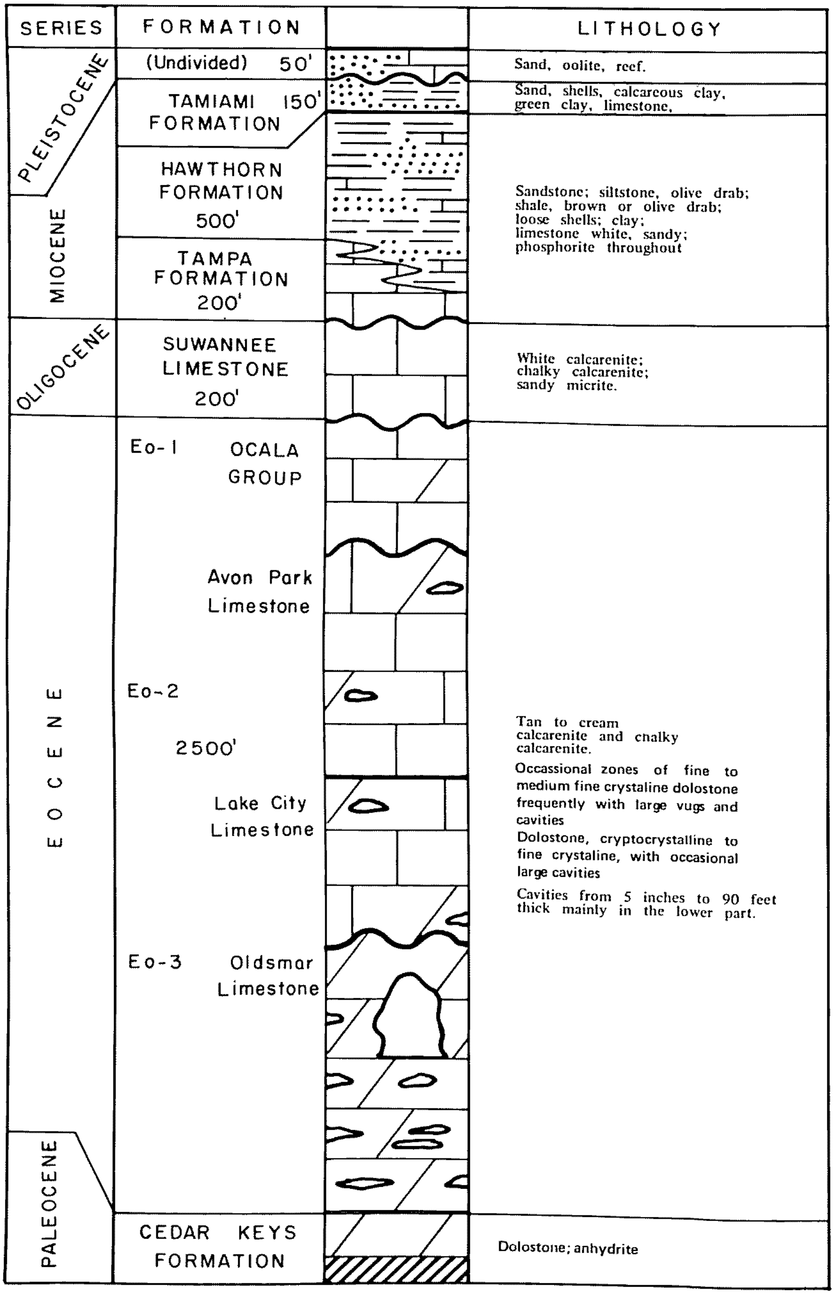


Figure 10 Generalized geologic column of the Cenezoic rocks.

BED	LITHOLOGY	CYCLE OF DEPOSITION	POROSITY
1		Limestone, white micritic, dense.	——
2		Limestone, white micritic, chalky.	Chalky
3		Packstone, white calcarenite 70% of skeletal grains 25% chalky matrix	5% granular & chalky
4		Grainstone, tan calcarenite 80-100% of fine to medium skeletal grains; many Foraminifera	10-20% granular
3		Packstone, white calcarenite 70% of skeletal grains 25% chalky matrix	5% granular & chalky
2		Limestone, white micrite, chalky.	Chalky
1		Limestone, white micrite, dense.	——

Eocene (Principally Avon Park)

Figure 11. Cycle of limestone deposition during the Eocene.

DOLOSTONE

Dolostone is usually dark brown or tan but may be dark gray, or light gray. Crystal sizes range from crypto to coarse and are anhedral, euhedral or sucrosic in arrangement; the sucrosic type is essentially a porous version of the euhedral variety. The anhedral form is the most common and the sucrosic form the least. These dolostone types can change from one to another in a fraction of an inch.

Additionally, dolomite is found as separate crystals "floating" in micritic or chalky limestones. These crystals range from micro to coarse grain in size, and their concentration ranges from an occasional crystal to a 95% replacement of the limestone.

Dolostone in the Eocene occurs either as thick discrete beds, or as thin zones within limestone beds (Fig. 10). In Eo-3 (Fig. 12) the dolostone forms a major portion of the section. In Eo-2 (Fig. 13) it is a major constituent only in the extreme northwest part of the study area; in Eo-1 (Fig. 14) it is a major fraction only in the northern part. Examination of the well cuttings indicates that dolomitization took place preferentially in the chalky matrix limestone type.

ANHYDRITE

Anhydrite is a minor constituent regionally, but can be of some importance locally. It is confined to Eo-3 and Eo-2 (Figs. 12 and 13). In Eo-3 it is found in the western part of the study area as beds or as nodules. It is white to gray, transluscent and amorphous in texture. In Well 30 several thin beds of dark brown crystalline anhydrite occur. This occurrence, of local origin, is probably related to an Eocene collapse zone on the Sunniland Field structure.

Eo-2 anhydrite is also both bedded and nodular, and is confined to western Collier County and Manatee County.

LIGNITE AND PEAT

In Eo-3 peaty partings and very thin layers of peat are common, occuring in a southward trend through the central part of the area (Fig. 15). Lignite was not observed in this unit.

In Eo-2, peaty partings, peat and lignite all are found in a trend extending southeastward across the study area (Fig. 15). Several beds of lignite were present in Well 1 and Well 13. Lignite varies in thickness from a trace (Well 48) to 30 feet (Well 1).

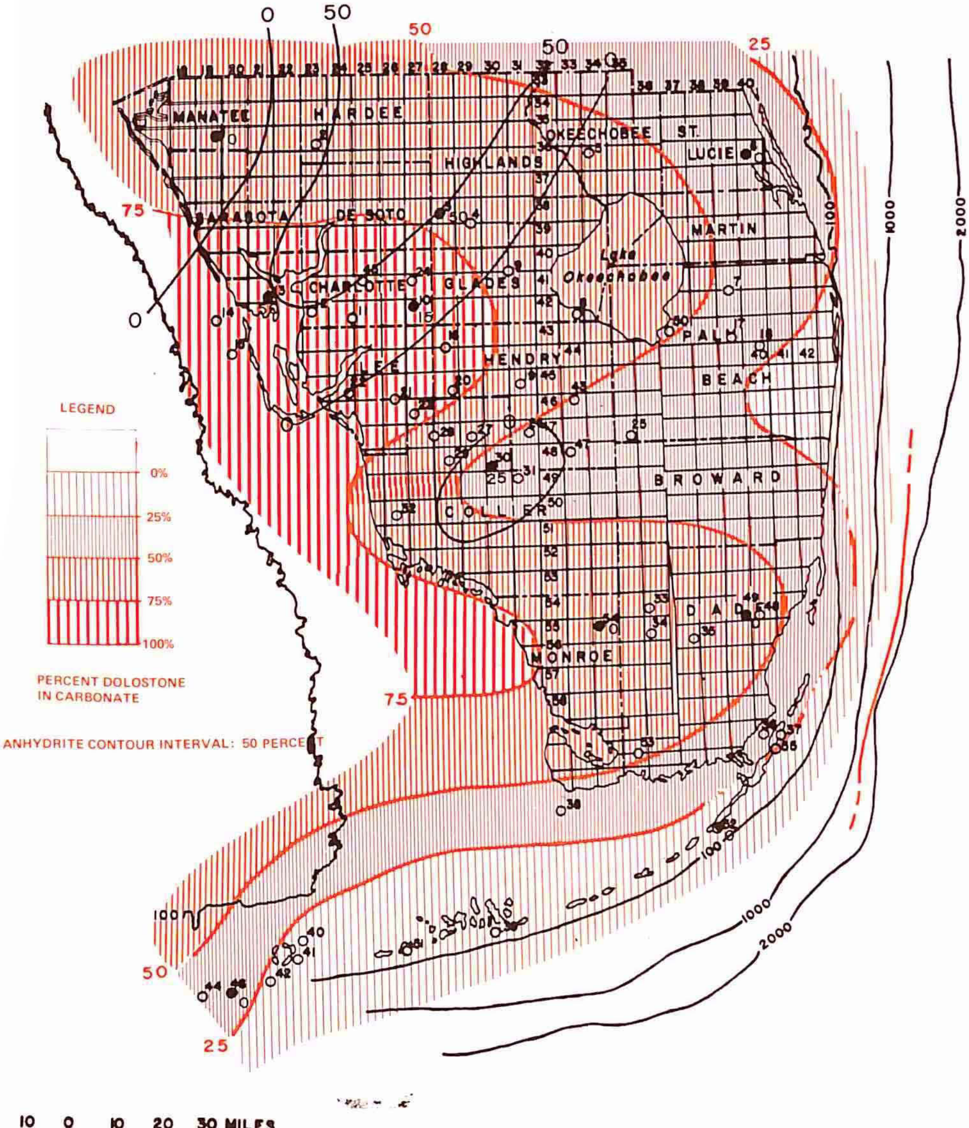


Figure 12 Map showing percent dolostone in carbonate and percent anhydrite in Unit Eo-3.

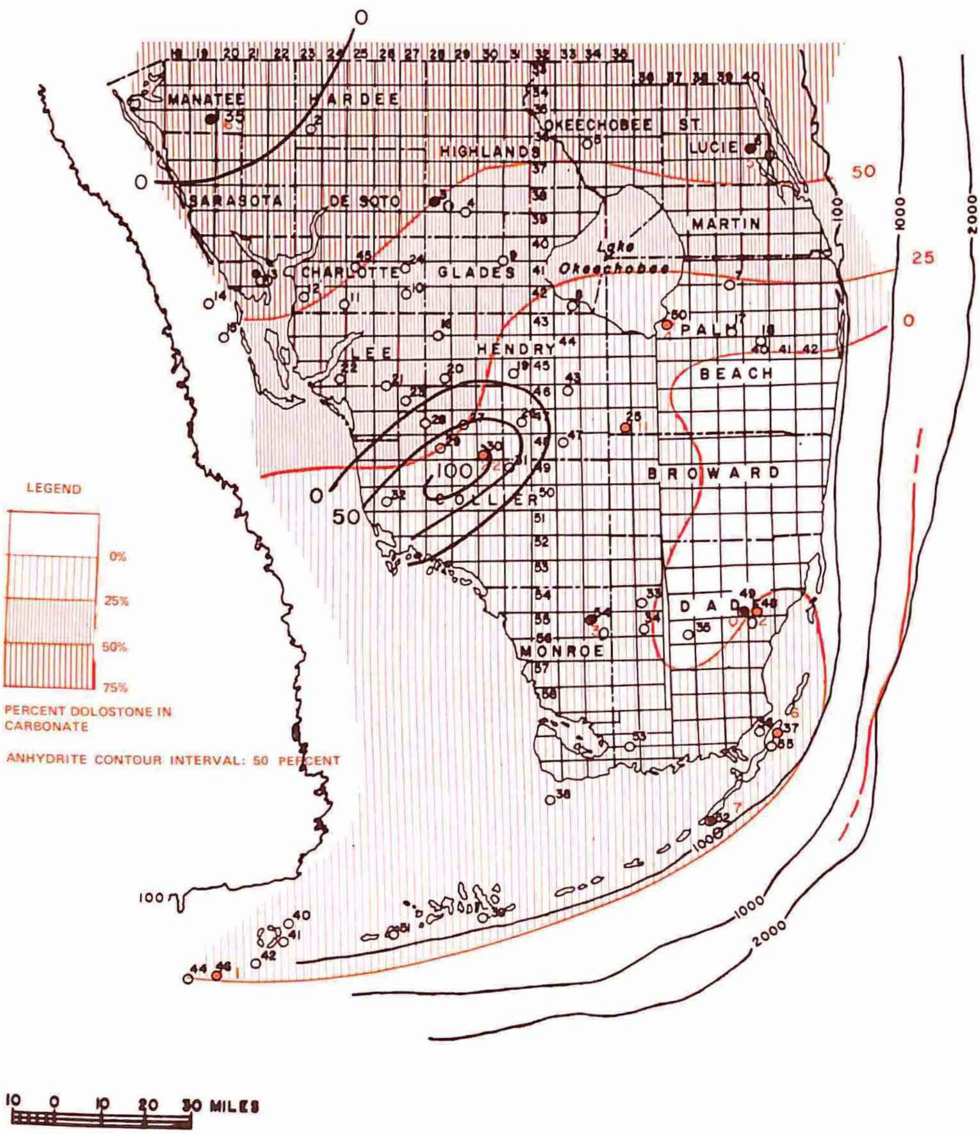


Figure 13 Map showing percent dolostone in carbonate and percent anhydrite in Unit Eo-2.

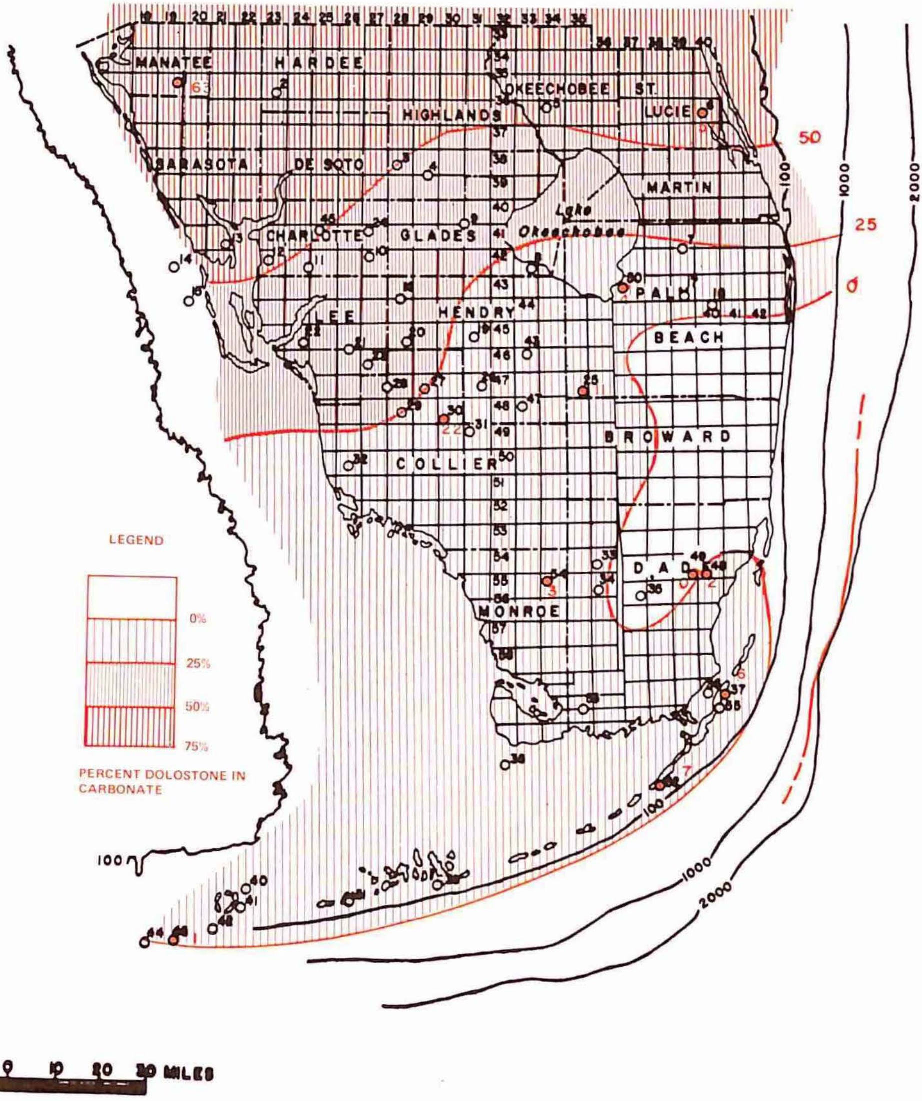


Figure 14 Map showing percent dolostone in carbonate in Unit Eo-1.

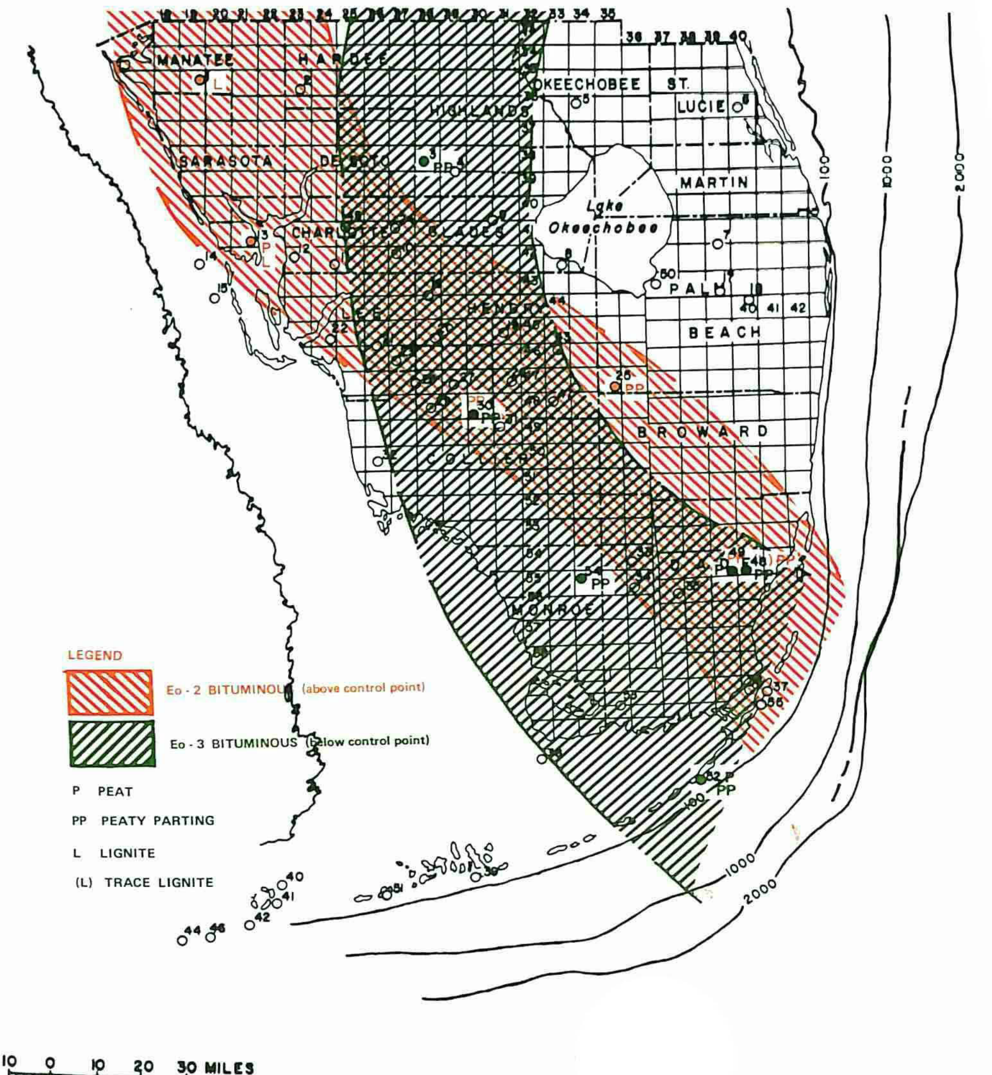


Figure 15 Map showing Eocene bituminous occurrences.

THICKNESS

Thickness of the total Eocene varies between 2300 feet and 2960 feet, averaging some 2600 feet. (Fig. 16).

Thin areas occur over the Martin, Largo, and Charlotte Highs (Fig. 2). Prominent thick areas are found in the central part of the study area and in the center of the Basin off the modern southwest coast.

As all units in each well had exactly the same thickness one isopach map suffices for all subdivisions (Fig. 17).

BOUNDARIES AND RELATIONSHIPS

The lower boundary of the Eocene with the Cedar Keys Formation is everywhere conformable. It is gradational in local areas, but electric log correlations can be easily made with occasional assistance provided by lithologic examination of well cuttings. The lower contact was picked on the sharp break at Cedar Keys Unit C. Here the beds change from grainstone or packstone of Units A/B (or dolomitized version thereof) at the top of the unit to a very fine and microcrystalline, euhedral, frequently sucrosic, gray dolostone below.

Units A/B are therefore included in Eo-3. At times this contact may be difficult or impossible to pick in samples, but surprisingly the electric log character will remain quite consistent.

The upper boundary of the Eocene with Oligocene and Miocene beds is everywhere unconformable, exhibiting as much as 200 feet of relief (see Fig. 5). In the southeast part of the study area most of the Ocala portion of the Eocene is missing.

The percentage of grainstone carbonate (or absence of chalky matrix material) is greatest near the southeast coast and in the Keys, where most of the section tends to be composed of grainstone. To the northwest, the Eocene becomes progressively more chalky and is dominated by packstone.

AGE AND CORRELATION

The presence of lower, middle, and upper Eocene Stages are well established from the extensive fauna in these lithologic units. An attempt was made in South Florida to identify the boundaries of formations by microfauna, but extensive replacement by dolomite obliterated the finer features of the various species, and even in the limestone, diagnostic fossils were uncommon.

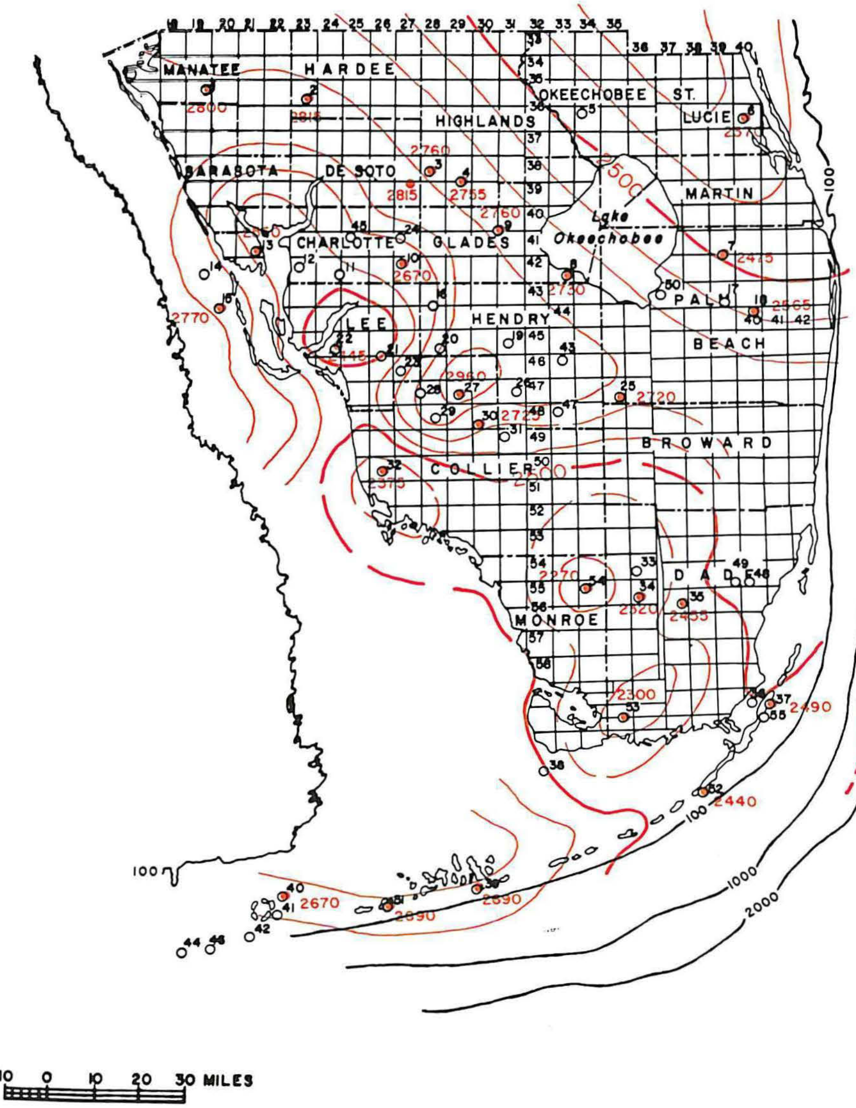


Figure 16 Isopach map of Eocene rocks.

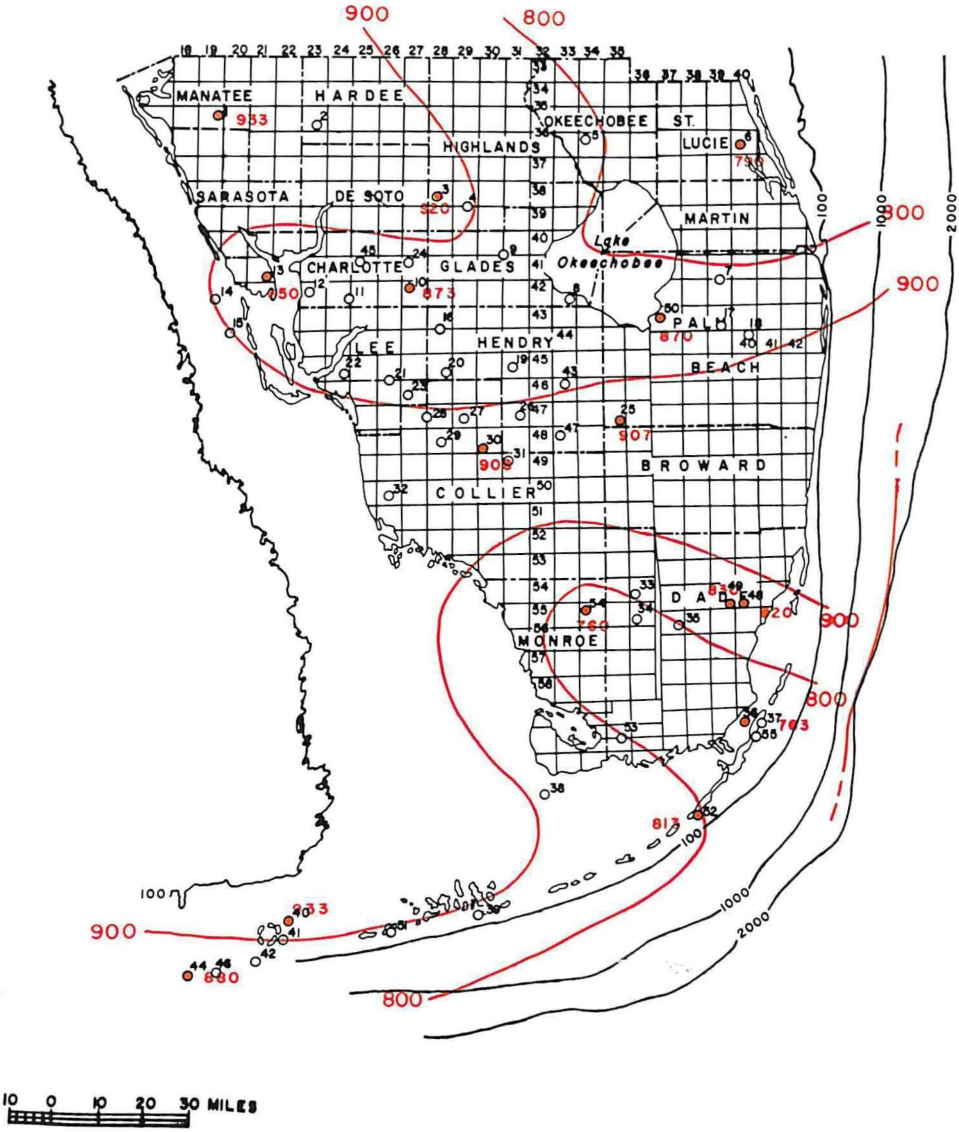


Figure 17 Map showing thickness of Eo-1, Eo-2, or Eo-3 in the Eocene.

Lack of good samples in most wells was also a handicap. Consistent paleontologic subdivisions of the Eocene in South Florida were not possible, with the exception of the Ocala at the top of the section. The Oldsmar tops vary widely between wells, and are not suitable for mapping purposes. Lack of any consistent lithologic horizon in the almost universally porous limestone, as well as the erratic nature of dolostone occurrence, precluded using lithologic parameters for subdividing the section.

Lacking lithologic or paleontologic criteria, the Eocene was, therefore, subdivided into three equal intervals in each well. These units in descending order are designated as Eo-1, Eo-2, and Eo-3, and are roughly equivalent (in Manatee County) to Ocala-Avon Park, Lake City, and Oldsmar paleontologic tops, respectively. That the top of the Oldsmar moves capriciously up and down the section has long been known. (see Fig. 18, 19) One contributing factor is dolomitization, which in some instances has destroyed diagnostic fossils, thus displacing the faunal top of the formation downward from the true top. Where dolomitization is not a factor, two other explanations can account for the lack of fossils.

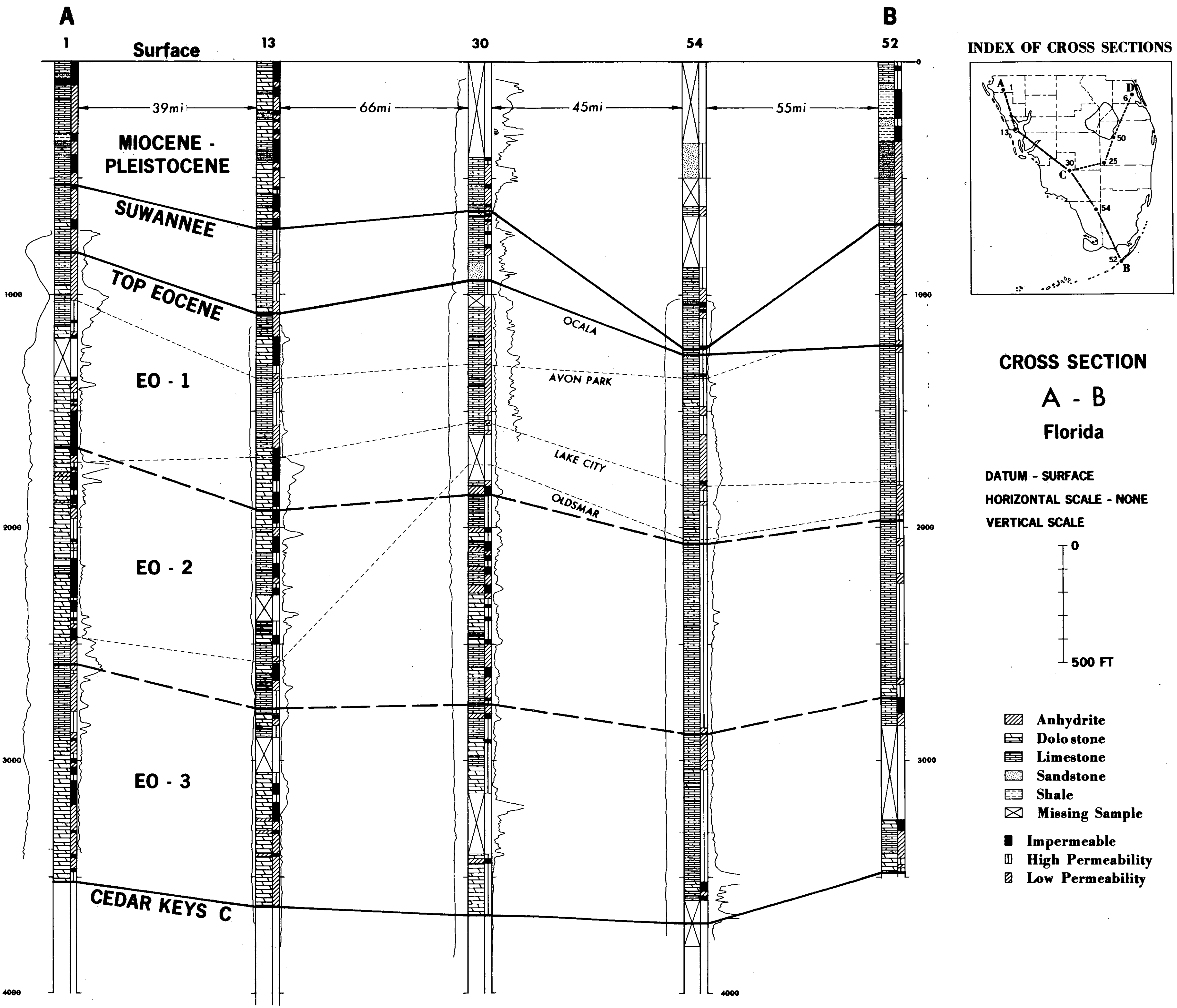
1. Larger Foraminifera, which are a major component of the fauna, thrive on open, lime bank facies, under normal saline conditions. Excessive run-off from the mainland would change salinity conditions, which are detrimental to their growth. Pure calcilutites or calcarenite (Suwannee and Ocala) invariably are associated with a true bank fauna. Fluctuations in sea level would cause the fauna to migrate seaward. Supersaline conditions in the area would discourage growth of normal saline forms. Occasional presence of anhydrite is indicative of supersaline conditions, which are detrimental to the growth of larger Foraminifera. Cyclic solution and replacement of calcite which was formed in some of the supratidal dolostones, would destroy tests.

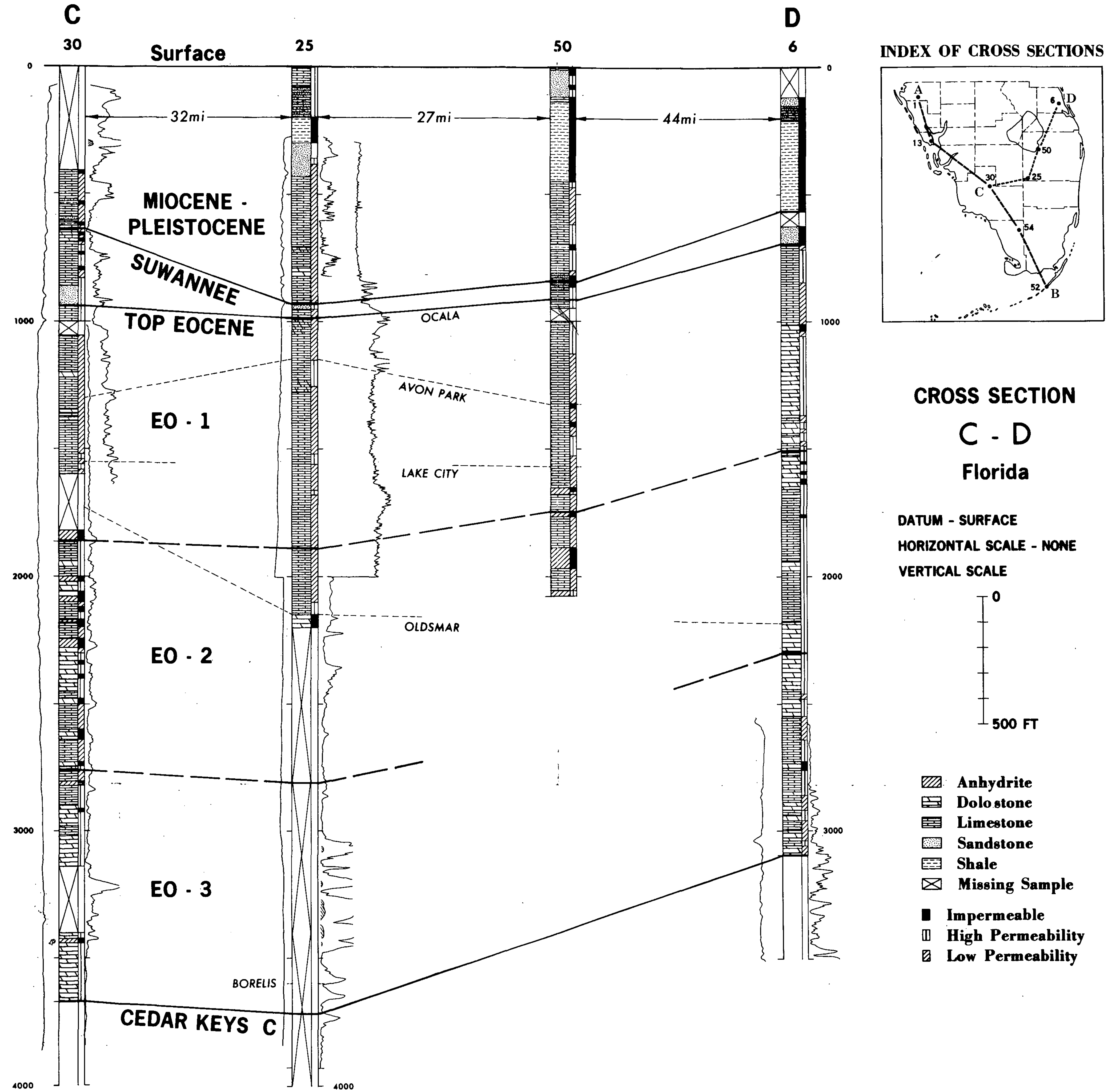
2. Another hypothesis that would explain the poor faunal record is the migration southward in space and upward in time of the environment in which bank forms existed. This hypothesis would not require tectonic activity other than the gradual sinking of the area, an activity characteristic of the Basin since the Jurassic.

HYDROGEOLOGIC CHARACTER

LIMESTONE

Permeable beds in Eocene limestone are associated with both the grainstone and with chalky packstone. In the grainstone, porosity in a few core samples was measured as high as 35% with permeability occasionally as high a 1


A
B
1
13
30
54
52
Surface
39mi
66mi
45mi
55mi
MIOCENE - PLEISTOCENE
SUWANNEE
TOP EOCENE
OCALA
AVON PARK
LAKE CITY
OLDSMAR
EO - 1
EO - 2
EO - 3
CEDAR KEYS C
0
1000
2000
3000
4000
INDEX OF CROSS SECTIONS
CROSS SECTION
A - B
Florida
DATUM - SURFACE
HORIZONTAL SCALE - NONE
VERTICAL SCALE
0
500 FT
Anhydrite
Dolostone
Limestone
Sandstone
Shale
Missing Sample
Impermeable
High Permeability
Low Permeability


C
D
30
Surface
25
50
6
0
32mi
27mi
44mi
MIOCENE - PLEISTOCENE
SUWANNEE
TOP EOCENE
OCALA
1000
AVON PARK
EO - 1
LAKE CITY
2000
OLDSMAR
EO - 2
3000
EO - 3
BORELIS
CEDAR KEYS C
4000
INDEX OF CROSS SECTIONS
A
1
13
6
D
50
30
25
C
54
52
B
CROSS SECTION
C - D
Florida
DATUM - SURFACE
HORIZONTAL SCALE - NONE
VERTICAL SCALE
0
500 FT
Anhydrite
Dolostone
Limestone
Sandstone
Shale
Missing Sample
Impermeable
High Permeability
Low Permeability

darcy. During drilling of wells, drilling fluid is frequently lost in this lithologic type. In chalky packstone beds, porsity in a few core samples was found to be as high as 33%, but permeability was low averaging 5 millidarcies. Although the chalky beds will transmit water, it will be at such a slow rate that they can be considered as aquitards rather than as aquifers. Dense limestone aquicludes in the Eocene are rare.

DOLOSTONE

Sucrosic dolostone can have porosity as high as 20% with excellent permeability. Vug porosity in dolostone is frequently low, but permeability can be quite high when the vugs are well connected. Porosity and permeability are extremely high in the cavernous zones.

The high porosity (23%), low permeability (2 millidarcy), microcrystalline or chalky dolostone would tend to act as an aquitard. Dolostone aquicludes are hard to evaluate. Although a considerable thickness of non-porous anhedral dolomite is usually present in Eo-3, its impermeable nature depends on the absence of fractures. Because fractures can rarely be identified in cuttings (the major source of lithologic data for this study) the regional state of fracturing could not be determined. The Sun Oil Company's photos of the Eocene in their Red Cattle 32-2 Well showed no large open vertical fractures. Lacking data to the contrary, we tentatively conclude that dense dolostone acts as an aquiclude.

POST - EOCENE

There is a major erosional unconformity at the top of the upper Eocene, which in South Florida is represented by the Ocala Group. Generally the Ocala Group is overlain by 200 to 300 feet of Suwannee Limestone, consisting of very porous, white, calcarenite, chalky calcarenite and sandy micrite. The base of the Suwannee Limestone is marked by the occurrence of *Streblus mexicana, S. byramensis,* and *Coskinolina floridana* and its top is marked by an abundance of *Miogypsina hawkinsi.* Where the Ocala Group is missing, in the southernmost peninsula and in the Florida Keys, the Suwannee Limestone unconformably overlies the Avon Park Limestone.

Oligocene Suwannee Limestone is overlain by lower and middle Miocene (Tampa Stage and Hawthron Formation) which consists of about 700 feet of intermixed varying lithologies and percentages of sandstone, siltstone, olivedrab shale, brown or olive loose shells, white sandy limestone, with phosphorite or plastic clay. The section, especially the clay, has a very low permeability and acts as an aquiclude over the porous and permeable Suwannee Limestone.

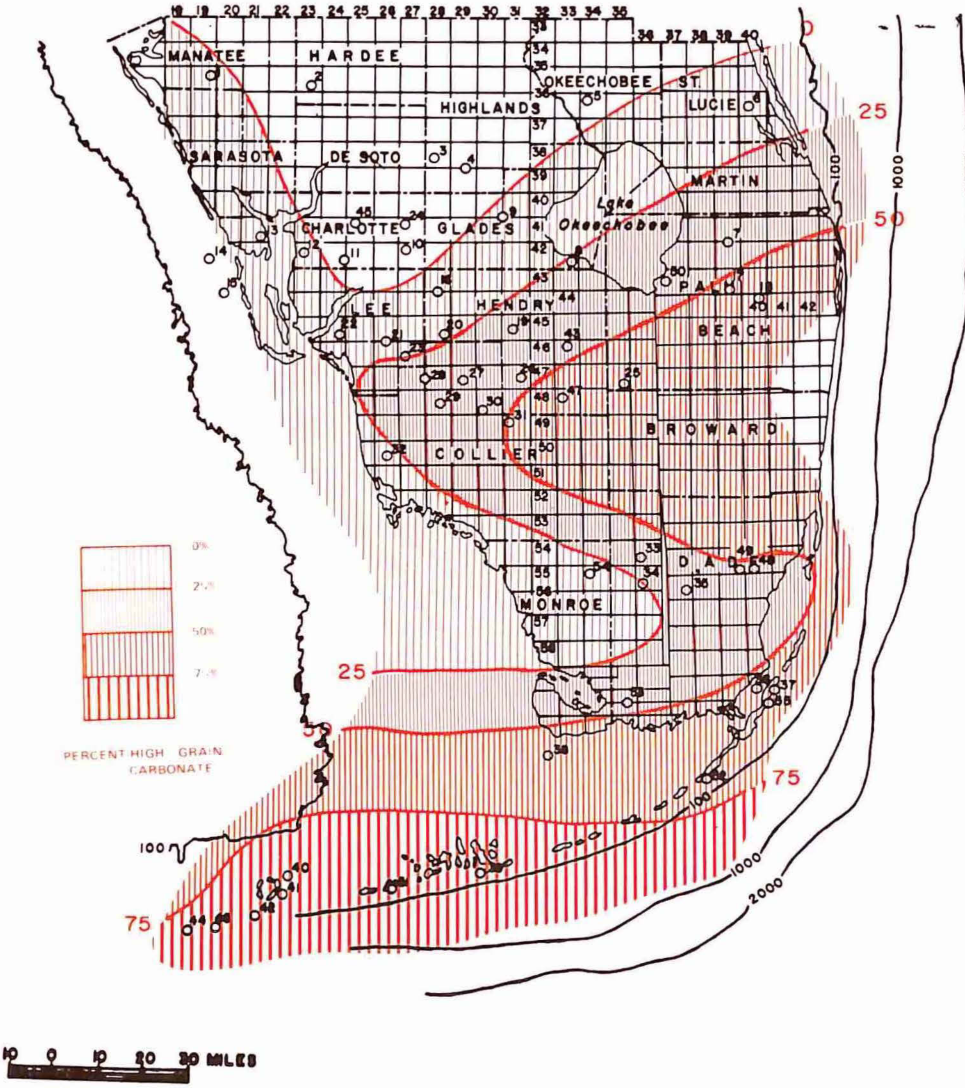


Figure 20 Map showing percent grainstone in Unit Eo-3.

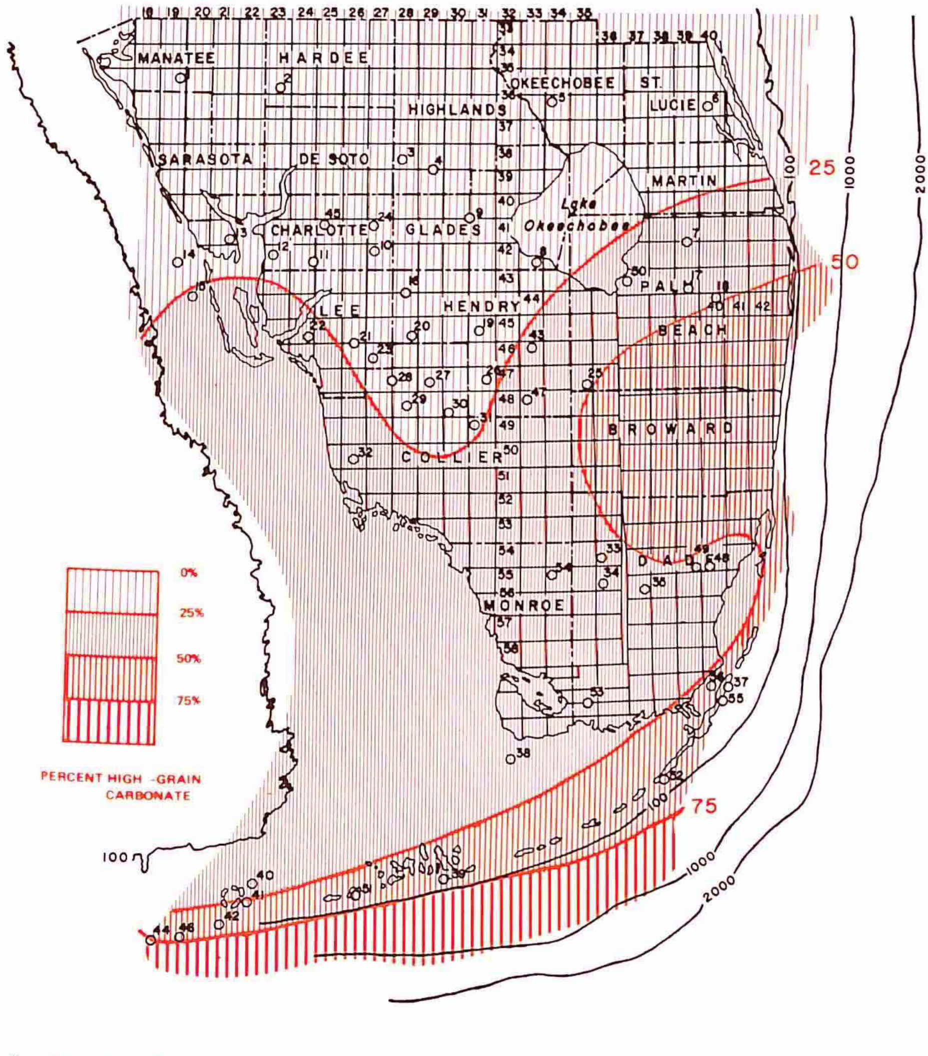


Figure 21 Map showing percent grainstone in Unit Eo-2.

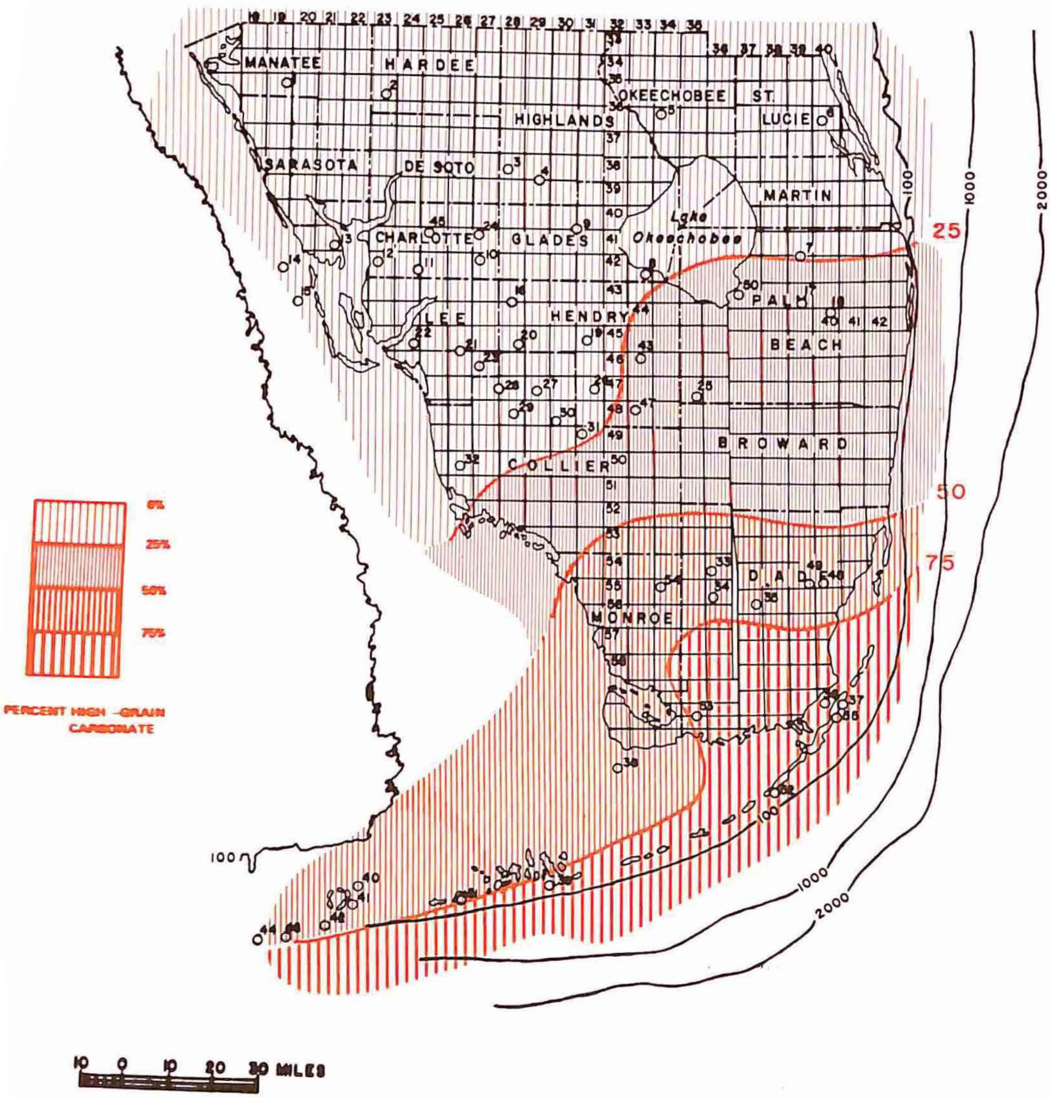


Figure 22 Map showing percent grainstone in Unit Eo-1.

Beds of the upper Miocene Tamiami Formation, consist of approximately 150 feet of limestone, calcareous clay, green-aluminous clay, and sand. The Miocene is overlain by Pleistocene, which includes numerous formations including the Miami Oolite, Anastasia Formation, Caloosahatchee Formation, Fort Thompson Formation and the Key Largo Limestone.

GEOLOGY OF THE HIGH TRANSMISSIVITY ZONES

DEFINITIONS

"BOULDER ZONE"

The beds referred to as the "Boulder Zone" contain no boulders. The zone was named by well drillers in the early days of south Florida oil exploration for an interval spanning the lower part of Eo-2 and Eo-3. This is the zone of great permeability and characterized by an intricate vug and large cavity porosity. Pieces of the rock forming the roof of an occasional cavity, collapse breccia, or cavern are broken off by drilling activity and these fragments fall into the hole, are rolled between the drill rod and the walls of the hole to create real "boulders" (Fig. 23).

Another phenomenon lending to "boulder" type drilling involves the loss of drilling fluids into these permeable zones. The fluid volume to the surface is reduced, and large cuttings which cannot be lifted by the reduced fluid flow settle to the bottom of the hole. These cuttings create pipe and bit-sticking problems which has drilling characteristics similar to drilling depositional "boulders". Where total or partial loss of fluid circulation occurs in the hole, "Boulder Zone" drilling problems can be expected to occur throughout that zone.

HIGH TRANSMISSIVITY ZONES

"High transmissivity zone" is a hydrologic term implying the ability of a thick vertical section to transmit fluids.

Five discrete zones of high transmissivity occur in cavernous carbonate beds of upper Cretaceaous, Paleocene and Eocene age and their distribution is shown on a generalized geologic cross section (see Fig. 24). The cavities tend to rise stratigraphically away from the Florida Straits in a northerly direction.

DATE QUALITY

The only reliable way to be able to obtain data on the position, shape and thickness of the cavities is to make a stereo-photographic survey. Unfortunately, this type of data is available on only one well (Sun Red Cattle 32-2).· Secondary data, such as drilling time logs, notations of "boulders", "cavity", or "caverns" interpretations from geophysical logs, or occurrences of lost circulation had to be used to indicate the general distribution of the zones of high transmissivity.

No isopach maps were prepared of the zones of high transmissivity, as data on the base of the zone was unobtainable. The top of these zones can be picked by using the above-mentioned criteria. As the lost circulation persists until the depth where the Eocene high transmissivity zone is cased off, there is very little available data to draw the base of zones.

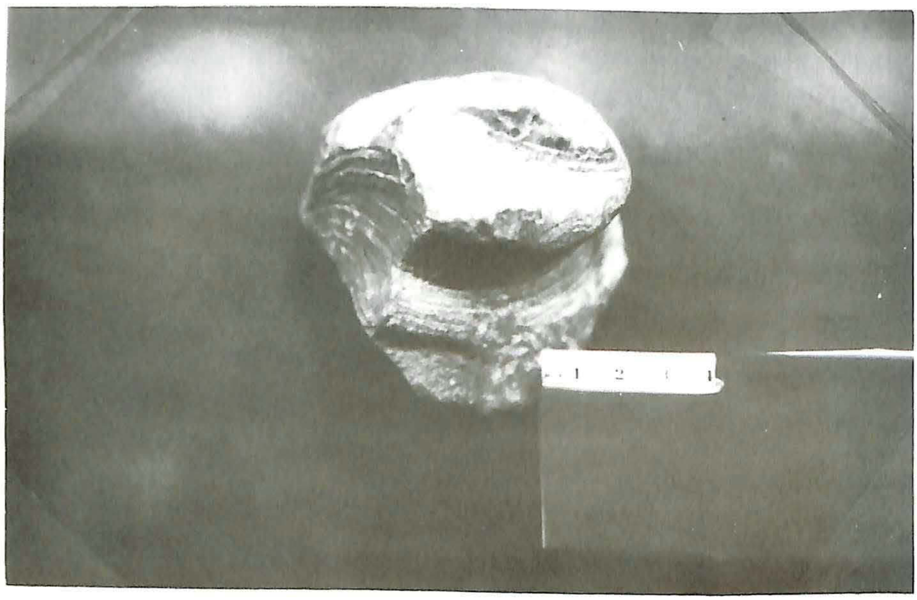


Figure 23 "Boulder" with two sets of tool marks from an unknown depth between 2200 and 2500 feet on the Amerada No. 1 Southern States (Well 7) Palm Beach County.

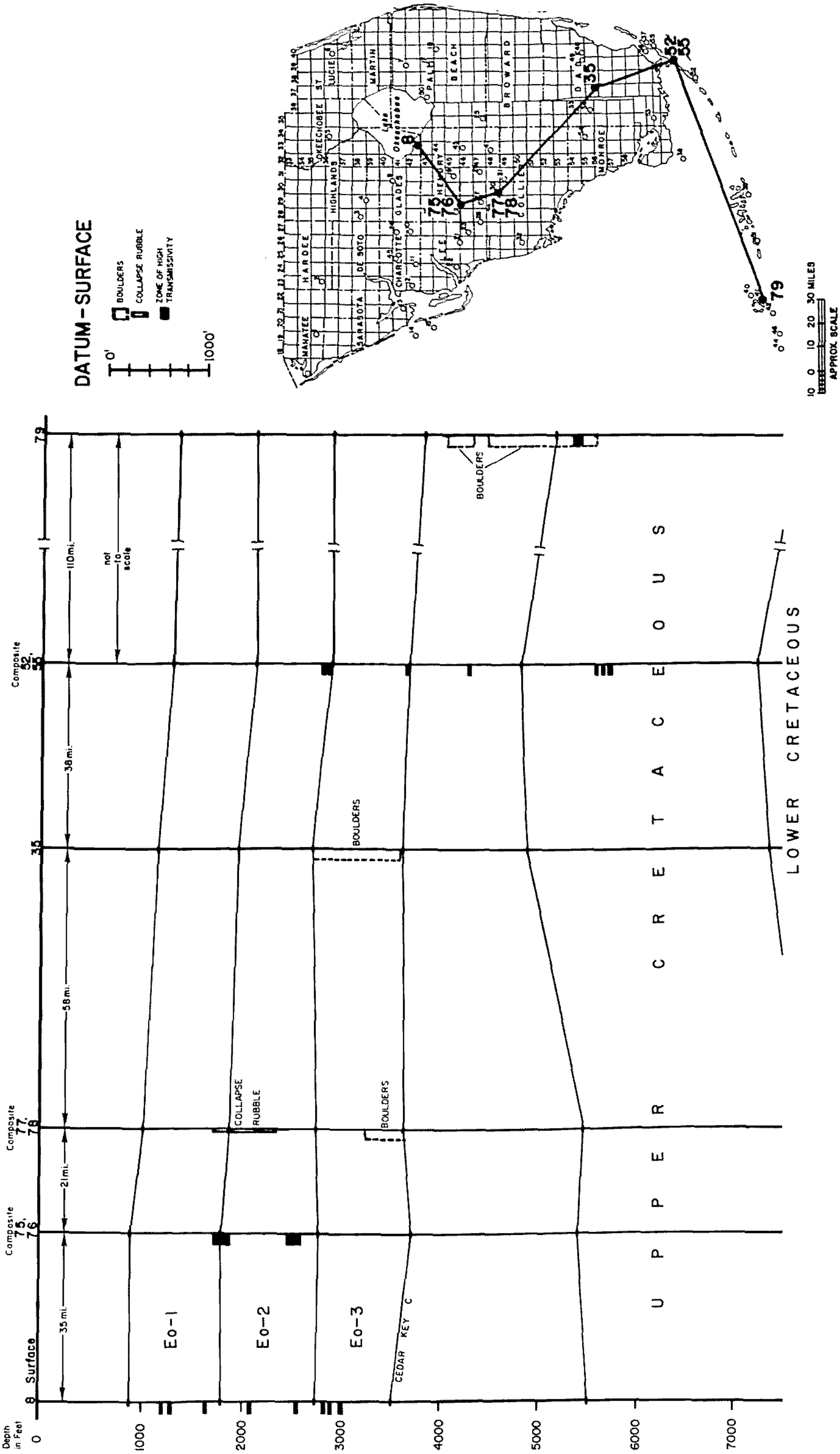


Figure 24 Generalized geologic cross section showing occurrence of zones of high transmissivity, collapse rubble and "boulders".

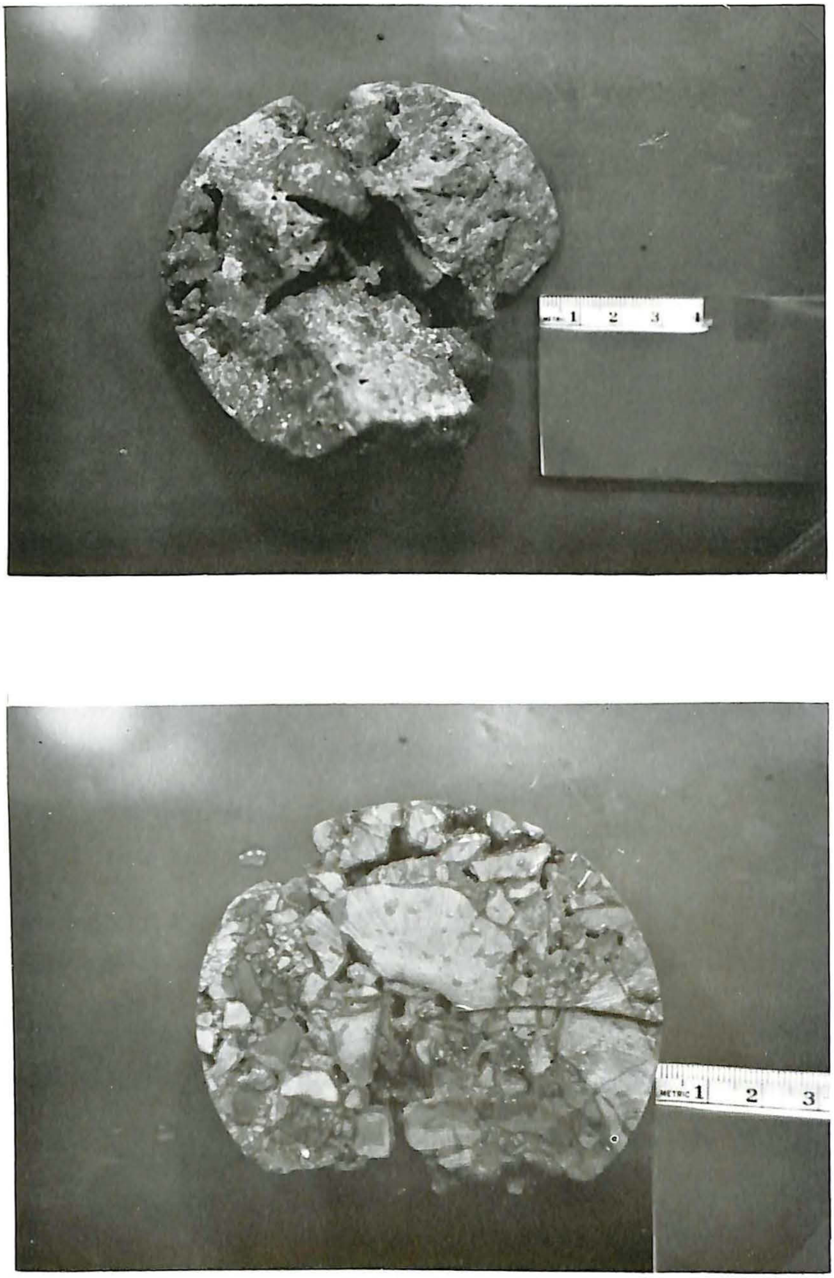


Figure 25 A sawed face of core from Upper Cretaceous 5034 - 40½ in Amerada No. 2 Cowles - Magazine (Well 6), St. Lucie County (top); Other side of the same core (bottom).

UPPER CRETACEOUS CAVITY ZONES

STRATIGRAPHIC SETTING

The Upper Cretaceous (Pine Key Group, Meyerhoff, 1973) in south Florida is composed almost entirely of limestone or dolostone chalk. This lithology is replaced in the **upper** part of the Pine Key Group, along the modern east coast and the Keys, by brown anhedral dolostone. In Wells 36 and 37, in the **lower** part of the Upper Cretaceous, the Card Sound Dolomite (Winston, 1971) of similar texture, replaces the chalk. Where the Card Sound Dolomite is present, the upper dolostone appears to be absent.

The upper dolostone was probably deposited at the back edge of a reef chain occupying an offshore position near the present continental slope forming the western side of the northern Straits of Florida.

A core contributed by E. J. Henderson (Figs. 24 to 28) from 5034 - 5040 feet in Well 6 shows a rubble rock, probably of reef talus, characterized by round fragments. The fragments, some of which are algal, are tan to light brown,

Figure 26 **Sawed face of core from Upper Cretceous 5034 - 40 in Amerada No. 2 Cowles - Magazine (Well 6), St. Lucie County.**

and are microcrystalline anhedral dolomite. A few of the fragments were originally split in place and re-cemented. The fragments are incompletely cemented together by medium crystalline dolomite, apparently a replacement of calcite cement. The labyrinthine cavities between some fragments are lined with drusy dolomite crystals. Porosity in the two specimens varies 5 to 15%, with very high permeability.

DESCRIPTION OF CAVITIES

The geographical distribution of the Upper Cretaceous cavity zone is shown on Fig. 29. The initial holes drilled at well locations 6 and 41 were abandoned due to drilling difficulties caused by large caverns. All Upper Cretaceous cavities and caverns have so far been found near the base of a massive dolostone facies in the upper part of the system. Large cavities are encounted in modern reefs near the base (MacLeish, 1973).

Figure 27 Scanning Electron Microphotograph of the same core shown as in Figure 26, showing cementation by medium crystalline dolomite.

In Well 6, four cavities were encountered from 5120 to 5294 near the base of the massive dolostone section, the lowest and largest cavity measuring 17 feet from floor to roof. The offset well, 1320 feet to the south, missed the cavern.

Well 41 was abandoned due to drilling difficulties by encountering a 50 foot cavern at 5270 feet. A second effort, 1½ statute miles east, encountered a 42 foot cavern at 5210 feet. Considering the similar sub-sea elevation of these two caverns and their similar thickness, it is likely that both are part of the same system, if not the same cavern. This is the largest extent of a cavern system yet recorded in South Florida.

In Well 52, 3 cavities, the largest 8 feet in height, were encountered at the base of the massive dolostone facies.

Very little data are available from which to infer the lithology of the rock surrounding these large Upper Cretaceous cavities as circulation returns cannot be maintained and cuttings are not recovered. From drilling time above and

Figure 28 **Same as Figure 27, enlarged X1500 showing faces of crystals and intergranular porosity.**

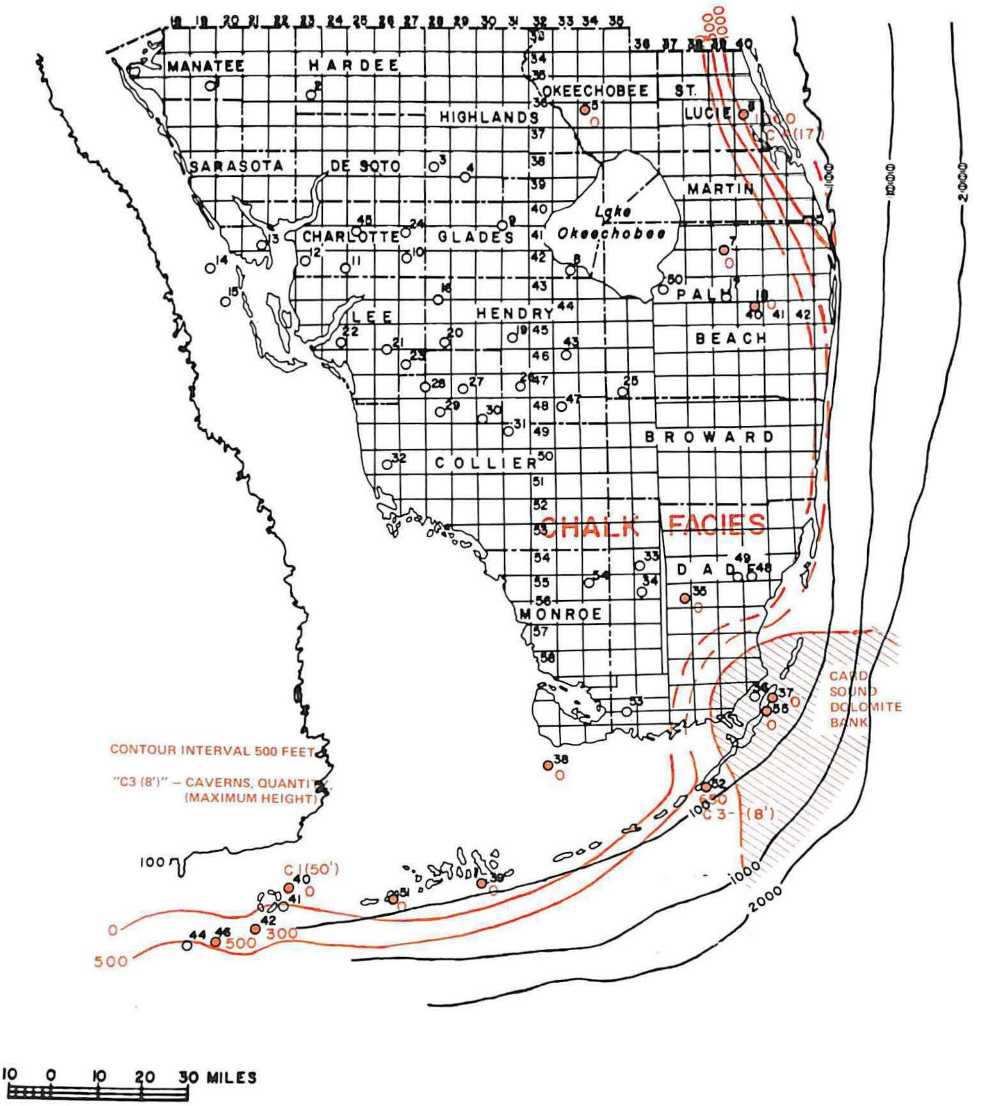


Figure 29 **Isolith map of upper bank dolostone and cavity distribution in Upper Cretaceous.**

below the cavity, and from lithologic data on nearby or off-set wells, the host rock is deducted to be light to dark brown, anhedral dolestone, the same lithology which hosts the Cedar Keys and Eocene cavity zones.

PALEOCENE CAVITY ZONES

STRATIGRAPHIC SETTING

The normal Cedar Keys lithology consists of a complex of micro to fine crystalline sucrosic dolostone interbedded with anhydrite. Along the Florida east coast and into the Keys, this lithology changes into a tan to brown anhedral dolostone with zones of porous euhedral dolostone (Fig. 30). This dolestone is similar in lithology to the Upper Cretaceous massive dolostone and probably also represents a back reef or bank deposit on the west side of the Florida Straits.

In Well 52 (Fig. 31), the electric log (no samples are available) indicates that a chalky type carbonate intervenes between the massive Cedar Keys and Upper Cretaceous dolostone. In Well 6, these dolostones are in contact.

DESCRIPTION OF CAVITIES

Two major cavities have been encountered in Paleocene bank dolostone. Several drilling reports of "boulders" (Fig. 30) have also been reported. From the incomplete data available, the Cedar Keys cavities appear to be scatterd within the massive dolostone.

In Well 55 a 50 foot cavernous zone was encountered in what on the electric log appears to be massive dolostone between 3510 and 3560 feet; an additional 15 foot cavern was encountered at a depth of 4285 - 4300 feet. No samples were obtained at these intervals due to lost circulation. In Well 6, 2 two-foot caverns at a depth of 3481 - 83 and 4232 - 34 feet, were encountered near the base of the massive dolostone. Well 44 was abandoned in the Cedar Keys due to drilling difficulties associated with high transmissivities.

EOCENE HIGH TRANSMISSIVITY ZONES

STRATIGRAPHIC SETTING

Examination of the U. S. Gypsum Core Test (Well 30), shows that the dolomite usually develops at a small distance beneath a peaty parting which is often immediately underlain by a bed of limestone pebbles imbedded in a micritic matrix; brown partings of unknown composition are frequently associated with this "beach rock". Below the peat or "beach rock" may be a

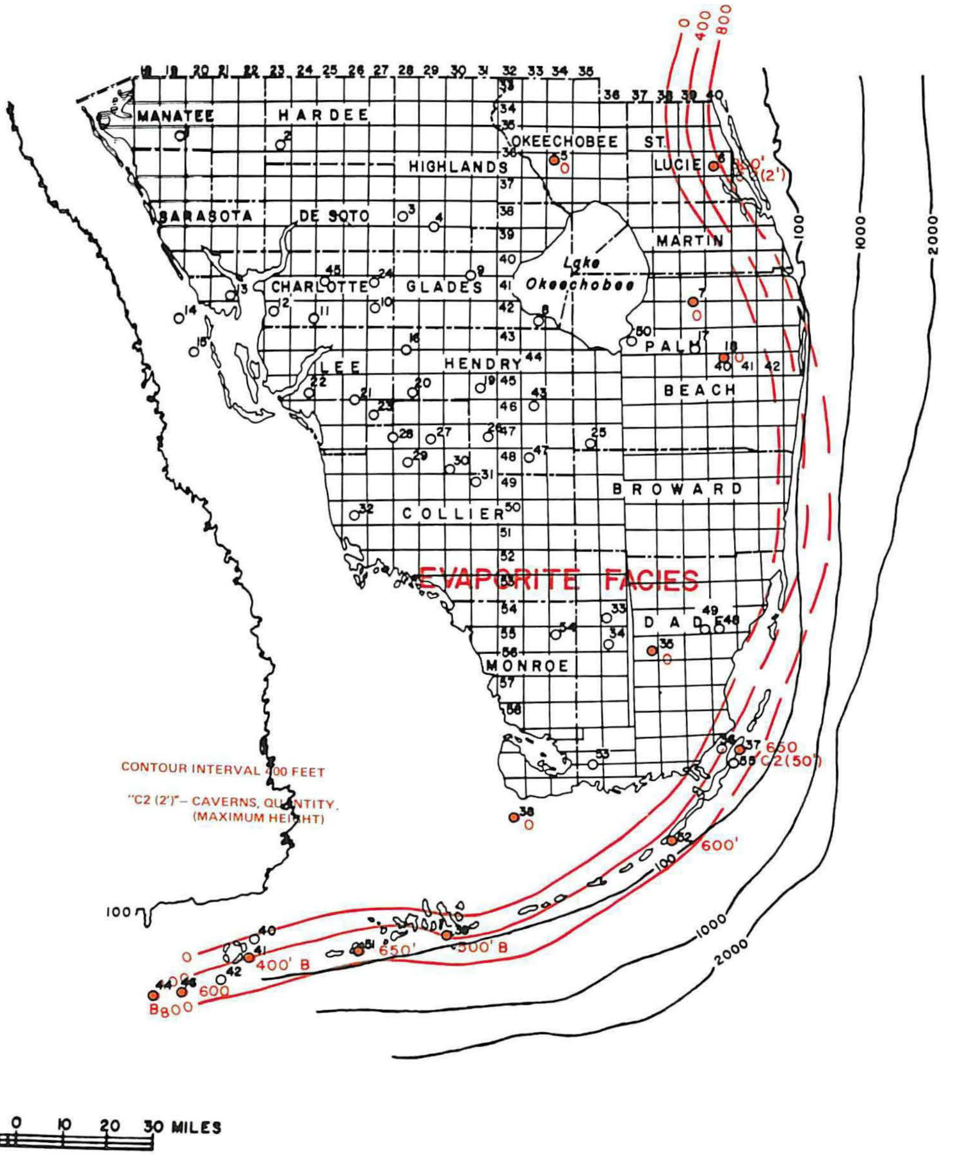


Figure 30 Isolith map of bank dolostone and high transmissivity distribution in Cedar Keys Formation.

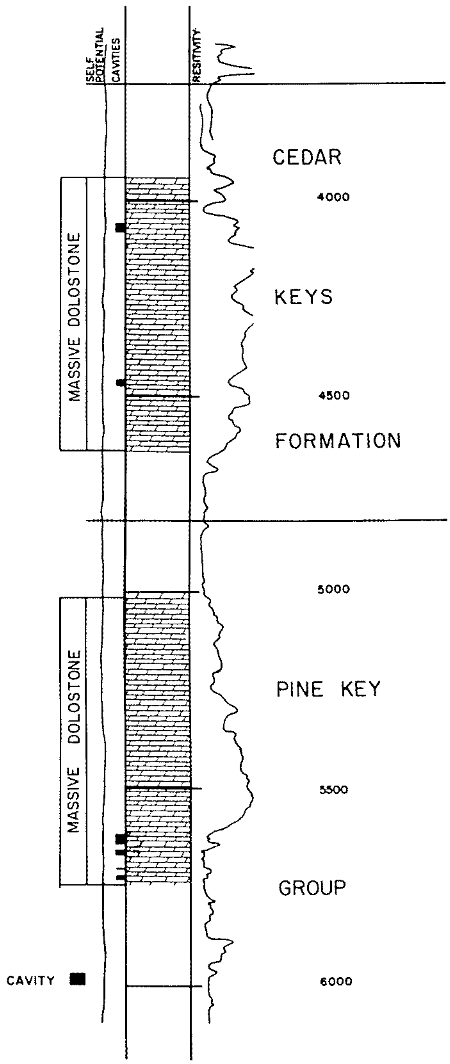


Figure 31 Generalized Cedar Keys and Upper Cretaceous bank dolomite sections based on Electric-log of Coastal No. 1 State (Well 52).

limestone with dolomite crystal inclusions; below this is fine crystalline, sucrosic, porous dolostone intermixed with non-porous anhedral dolostone of the same crystal size. This zone grades down into a medium crystalline euhedral, sucrosic or anhedral dolostone containing horizontally elongate vugs lined with drusy masses of dolomite crystals. Porosity in this zone runs from 10 to 20%. Beneath the dolomite is a thin zone exhibiting horizontal "partings" composed of very thin layers of dolomite crystals, or a limestone with imbedded dolomite crystals. Below this basal transition zone lies cream, chalky, skeletal limestone with brown partings. The cuttings from several of the wells examined showed similar features to these thin zones before losing circulation in the Eocene high transmissivity zones.

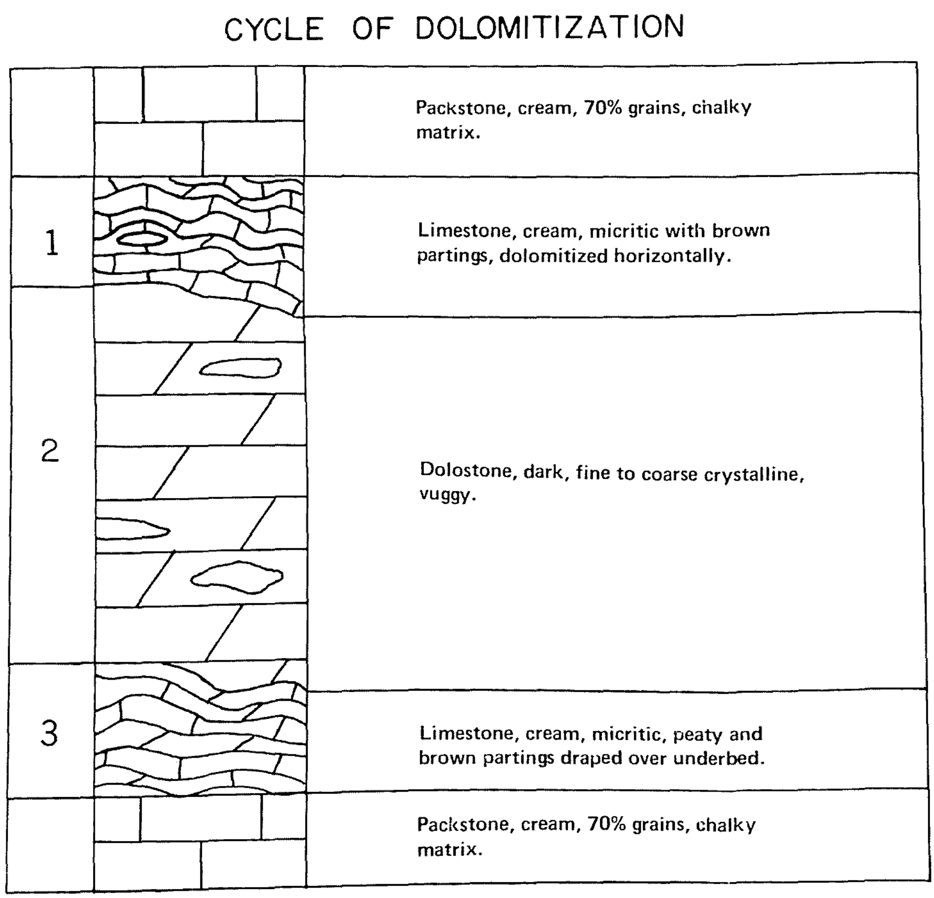


Figure 32. Cycle of dolomitization.

From examination of several of these dolostone zones we infer that a similar mode of development probably accounts for the larger cavity zones lower in the section. In Well 54, a thick section of cream chalky limestone containing masses of coarse dolomite crystals occupies the lower portion of the Eocene where elsewhere the cavity zone occurs. From this instance, from literature references, and from the association of similar lithology with the small cavity zones in the U. S. Gypsum Core, it is inferred that the replacement of limestone by dolomite, leading to the development of the large cavities took place in chalky limestone, rather than in grainstone. A generalized cycle of dolomitization based on their occurrence as observed in the U. S. Gypsum Core (Well 30) is shown on Figure 32.

DISTRIBUTION OF CAVITIES

Areal distribution of the zones of high transmissivity is shown on Fig. 33, 34, and Fig. 35. In Eo-3, the cavities occur over virtually the entire study area but are absent in the northwest part. On the Eo-2 map (Fig. 34), with two exceptions, the zone of high transmissivity is confined to the north central part of the area. The Eo-1 map (Fig. 35) shows two bands of development, one along the trend of the Keys, and the other an arcuate trend across the northern half of the map.

DESCRIPTION OF CAVITIES

Much of the Eocene zone of high transmissivity is composed of vugs in a labyrinthine arrangement. Most of the larger cavities are less than one foot, although, caverns of 63 (Fig. 34), 75 and 90 feet have been reported (Fig. 35). The well penetrating the 90 foot cavern was abandoned, and the offset 500 feet to the west missed the cavern.

Several zones of high transmissivity occur in a continuous core cut by U. S. Gypsum Co. (part of Well 30) to a total depth of 2055 feet. One of the best developed of these zones is described below. Several more of these zones are illustrated in Figures 36, 37, 38, 39 and 40.

DEPTH	THICKNESS	DESCRIPTION
		Overbed Limestone, cream, micrite; black very fine grained inclusions; chalky porosity.

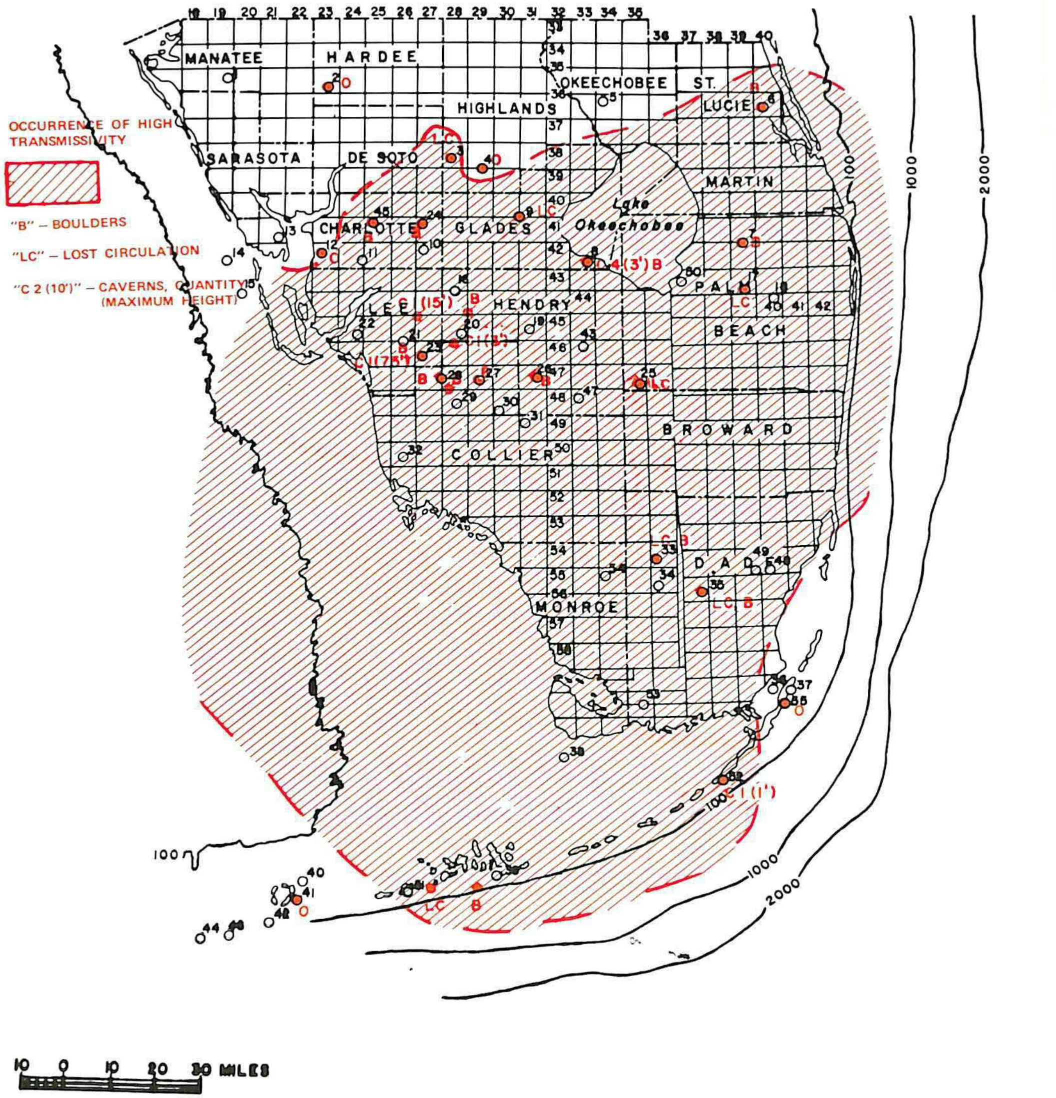


Figure 33 Occurrence of high transmissivity in Unit Eo-3.

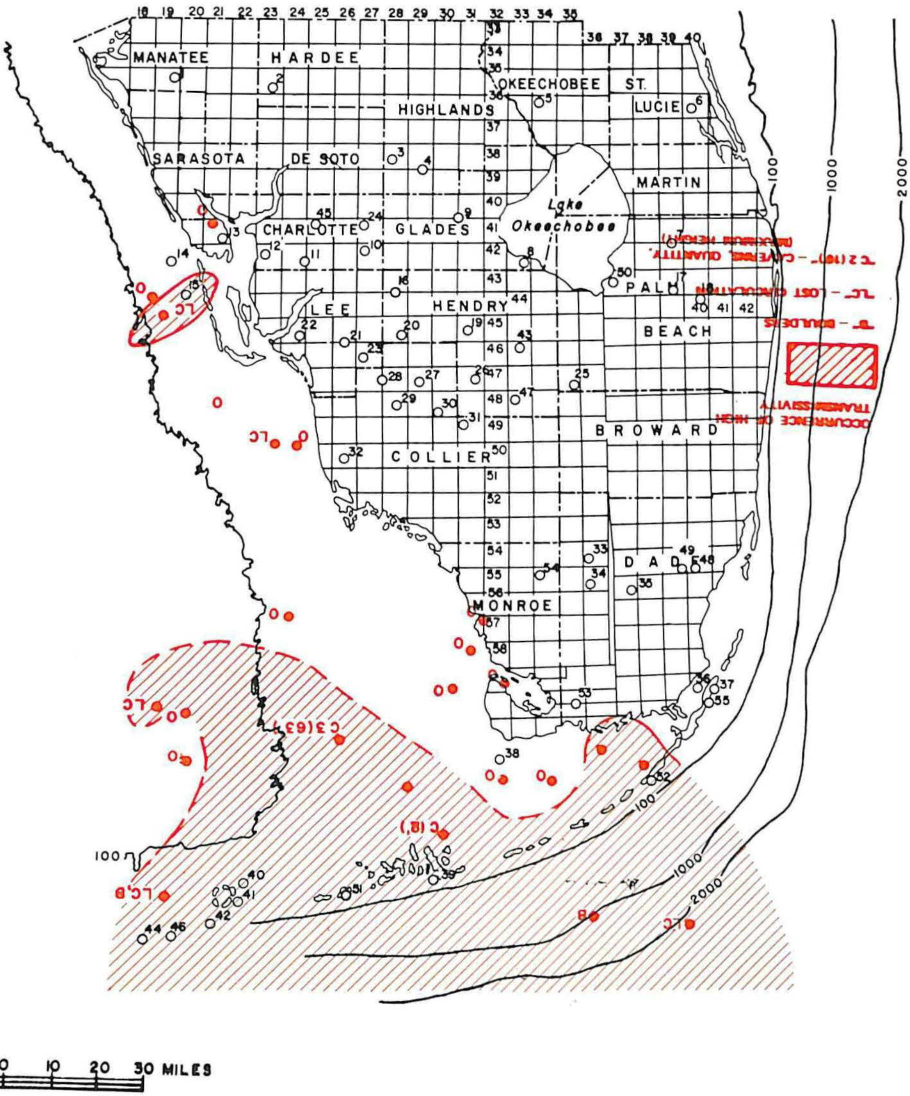


Figure 34 Occurrence of high transmissivity in Unit Eo-2.

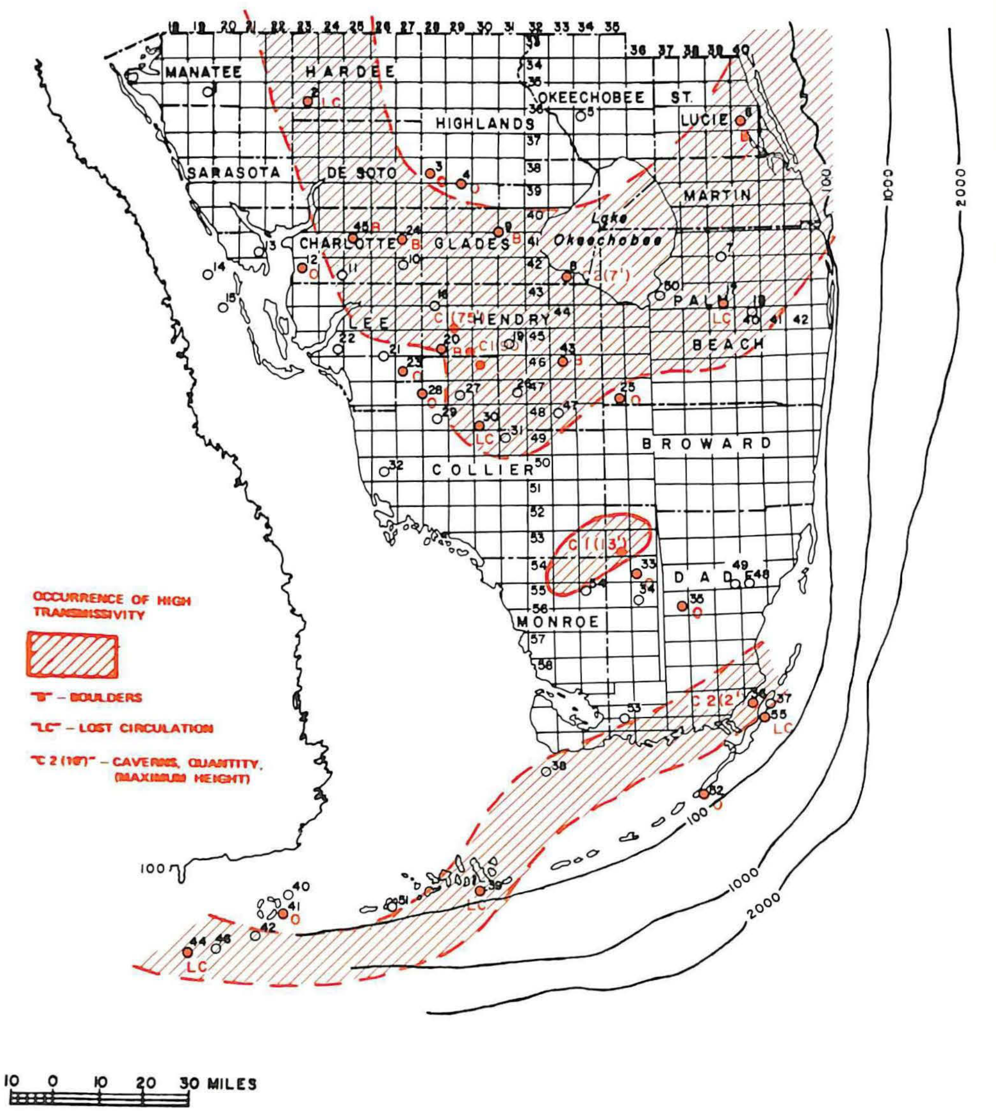


Figure 35 Occurrence of high transmissivity in Unit Eo-1.

Figure 36 Photograph of upper dolomite zone at 2030 feet in U. S. Gypsum Core (Well 30) showing peaty partings, "beach rock" rubble, and sucrosic dolomite zones.

Figure 37 Photograph of the top of the dolomite zone at 2046 feet in U. S. Gypsum Core (Well 30) showing peaty partings and limestone in irregular contact with incompletely dolomitized limestone.

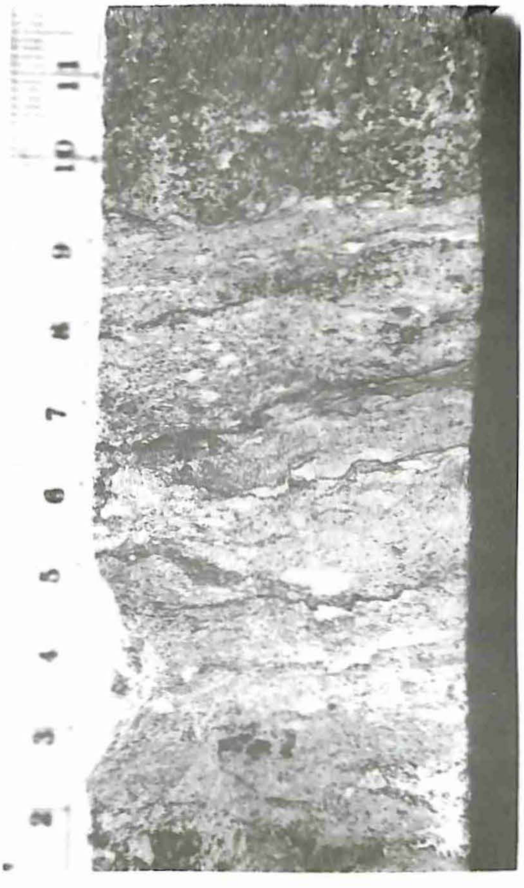


Figure 38 Photograph of the basal contact of the dolomite zone at 2046½ feet in the U. S. Gypsum Core (Well 30) showing dolomite grading into incompletely dolomitized limestone, underlain by peaty partings in limestone with dolomite crystal inclusive.

DEPTH	THICKNESS	DESCRIPTION
2042		
	0.5"	Sloping contact with lithology below characterized peaty parting.
	0.1"	Limestone, tan; coarse grained, white flat pebbles and brown partings.
	0.6"	Dolostone, tan, medium crystalline
	1.5"	Sloping contact

Figure 39 Photograph of the core at 2050 feet in the U. S. Gypsum Core (Well 30) showing preferred horizontal orientation of vug porosity in dolomite zone.

DEPTH	THICKNESS	DESCRIPTION
	3.0"	Dolostone, dark brown, anhedral; limestone, white chalky, up to 1/2 inch in size; shape blocky or flat, occasional vugs up to 0.2"
	4.5"	Dolostone, tan very fine crystalline euhedral; and pinepoint vug porosity.
	1.5"	Dolostone, brown, anhedral, very fine crystalline; 0.1" vugs.
	4.3"	Dolostone, tan, fine crystalline, euhedral; 10% intercrystalline porosity.

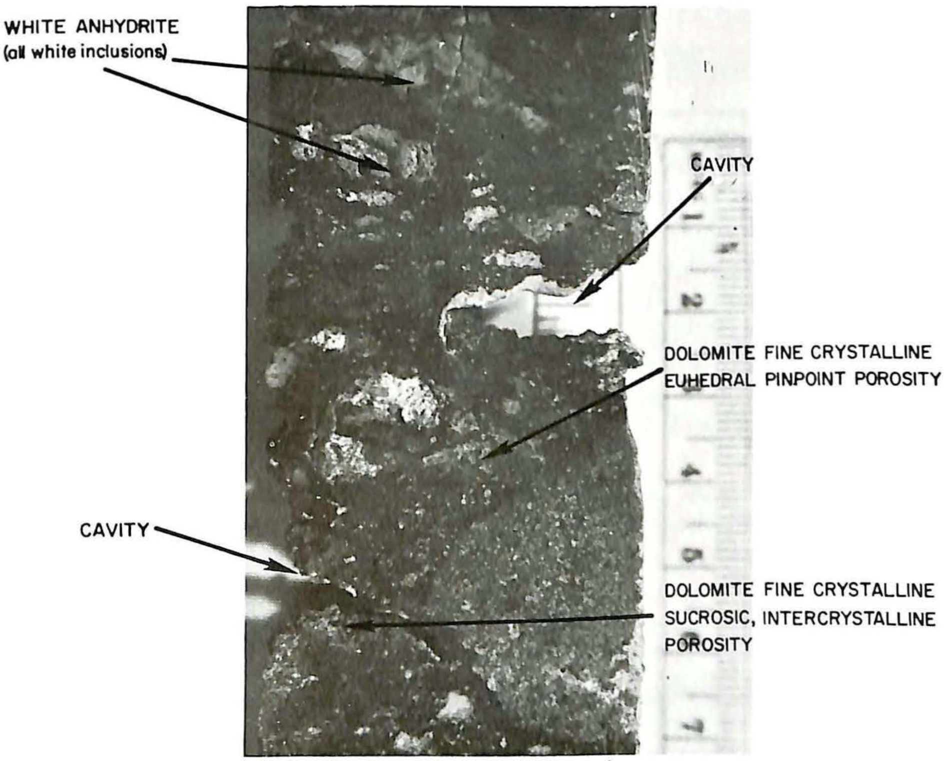


Figure 40 Sawed face of same core in Figure 39.

	0.3"	Limestone, cream, micrite, chalky with partings and/or crusts of dolomite crystals; peaty parting, limestone, cream, micritic, chalky; streaks of dolomite, very fine crystalline.
2044		
	0.1"	Sloping contact Underbed Limestone, cream, micrite, chalky; brown parting.

Some 180 stereo photographs were taken by the Sun Oil Company from 1300 to 2616 feet in their Red Cattle 32-2, Hendry County, Florida. Data on the size, shape, and vertical distribution of the cavities in the zone of high transmissivity, generally occurring from 2000 to 3200 feet in that area are given in Appendix 2.

Although it was not possible to identify openings less than 1 inch in size, several conclusions can be made concerning the larger cavities.

1. There is a marked preference of horizontal distribution and shape. Overwhelmingly the most common are cavities with a 2:1 horizontal over vertical dimension ratio. Cavities with round cross-section are rare.
2. Cavities with a vertical dimension of 3 to 4 inches are the most common, cavities over 5 inches were uncommon; those over 12 inches were rare.
3. Although isolated cavities were observed, most tend to occur in horizontal zones some 1 to 2 feet thick.
4. Cavities with a horizontal dimension larger than the hole size were frequently encountered. They ranged from 3 - 6 inches high, and occurred not only singly, but also in multiples, forming a "pancake stack" of cavities with only inches of dense dolostone separating them.
5. A number of "tunnels" were observed. These are equidimensional cavities which are found on opposite sides of the bore hole, and are construed to be the tunnels which the bore hole apparently cut. Cavities identified as such are isolated; in large groups of cavities this type relationship would be difficult to establish.

6. An observed odd-shaped cavity cross section included 2 isosceles triangles and a square.
7. Large caverns are extremely rare. In this well only one was encountered, some 90 feet in height. It is the next largest yet recorded in south Florida (largest 100 feet high, 6 miles west).
8. Vertical cavities are very rare.
9. Vertical fractures were not seen.
10. Several paired scratches on the walls probably from withdrawing the drill rod can be misinterpreted as vertical fractures.

HYPOTHESES OF ORIGIN OF CAVITIES AND DOLOMITIZATION

As we have as yet insufficient data to back up our ideas on this subject, and since the origin of the cavities and solutional interstices is not of primary importance in this descriptive report, we are not proposing a hypothesis of our own at this time. As all cavity and solutional interstices occur in dolostone, a review of the literature on the process of dolomitization is in order.

DOLOMITIZATION

a. Modern:

Observation of field conditions under which modern dolomite is forming, as well as laboratory experiments, have shown that certain conditions are necessary for the replacement of calcite by dolomite:

1. **High salinity** (200,000 PPM ? ?). An arid climate was the only mechanism so far reported which produced salinities of the necessary concentration.
2. **High Mg-Ca ratio.** Field observations showed that this condition was produced by the removal of calcium, either by organic processes or by precipitation of $CaSO_4$, thus leaving behind a large surplus of magnesium.
3. High pH (9 or more) was observed in all occurrences of marine-associated dolomite.
4. Tidal flat dolomites consist of crusts of dolomite rhombs.

b. Ancient:

Some field observations concerning dolomitization in ancient rocks which are applicable to the present problem follow:

1. Organic activity, principally bacteria and algae, may either precipitate dolomite, or cause conditions to become favorable for dolomitization principally by controlling the pH in shallow lagoons. Some organisms are much more susceptible to dolomitization than others. Among the most susceptible are the calcareous algae.
2. Dolomitization is frequently associated with disconformities; all known Recent occurrences have been so associated.
3. Fine grain, high-porosity, low-permeability calcium carbonate sediments are the preferred sites of dolomite replacement. It is suggested in this connection that replacement of grainstone, when it occurs at all, probably occurs during lithification when the formation waters are concentrated and driven out by compaction.
4. Several field observations concluded that porosity in dolostone resulted from the solution of limestone from a dolomite rhomb matrix, not from the process of dolomitization itself.

HYPOTHESES OF CAVITY ORIGIN

Dolomitization is critical to the formation of the cavities, as all cavities occur in dolostone. All hypotheses stand or fall on the time of dolomitization. So far, there is no evidence to conclusively prove when this took place.

Previously expressed hypotheses include those of Vernon (1947, 1951, 1971) and Kohout (1965), and Hanshaw, Back & Dieke (1971).

Vernon (1970) proposed a geochemical reaction that follows the mixing of two bodies of water that contrast in concentration of salts. The interface is the locus of dolomitization and of an intensified solution and removal of solids.

Kohout proposes a convection current, generated by geothermal heating of sea water freshly intruded into the high transmissivity zone from the rock outcroppings in the Straits of Florida at the east, south, and west sides of the Floridian Plateau. Dolomitizing magnesium-rich water is thus continuously circulated into the aquifer to provide the magnesium for continuous dolomitization.

A geochemical hypothesis for dolomitization by ground water was offered by Hanshaw, Back, and Deike (1971). Their study was based on chemistry of the Floridan ground water and the mineralogic composition of the artesian aquifer. They observed that there was a systematic change in the magnesium to calcium ratio from 0.5 in the potable water to 1 from the recharge area down-gradient into the deeper part of the aquifer system. They examined stable carbon isotope composition of calcite-dolomite and found that the calcite $\delta\ C^{13}$ composition is always that of normal marine limestone; however, the $\delta\ C^{13}$ of the associated dolomite was not formed under marine conditions but was formed under the effect of ground water, perhaps saline.

From our incomplete data in this study, we observed that the base and top of cavity zones in cores are usually bounded by peaty partings, or other impediments to vertical migration of fluids. The dolomitizing fluids then were forced to spread laterally, creating the horizontally oriented cavities and zones of cavities.

EVALUATION OF THE ZONES OF HIGH TRANSMISSIVITY FOR LIQUID STORAGE

The principal concern in the use of the subsurface for waste storage is the possibility of seepage into near-surface or deeper artesian aquifers used for drinking water. Data from this study can help allay these fears as follow:

1. Over the study area, several hundred feet of Miocene shales or plastic clays provide an effective aquiclude, in the unlikely case of the fluids reaching that point.
2. Although aquicludes within the Eocene are usually thin and few in number, thick Eocene limestones of low permeability overlie the zone of high transmissivity. These beds, if they transmit water at all, would act as filter beds, which chemically or physically should purify the transmitted water on its upward journey.
3. Such aquicludes as are present in the Eocene are of limited horizontal extent. (See Fig. 41, 42, and 43). When present, they would divert ascending non-acidic fluids into a tortuous path several times as long as that directly to the surface. This longer path would allow even more time for the water to be purified.
4. From our study, there is no known evidence, nor any reason to suspect the presence of vertical connections between the Upper Cretaceous, Paleocene, and Eocene cavity zones. All evidence shows that they are separate, therefore, the older two should make excellent storage reservoirs, either for fresh water or well-treated nonacidic effluents.
5. From studying the photographs of the Eocene zone in the Sun Red Cattle 32-2, it can be observed that horizontal permeability is overwhelmingly dominant over vertical permeability. Vertical permeability is rare through the dense dolostone separating

horizontal cavity zones. The vertical connections which do exist appear to be very short.

6. Large caverns, if commonly found, could be used for injection purposes.

RECOMMENDATIONS

1. In order to reduce the chances of surface contamination to a minimum, the fluids should be injected into the base of the high transmissibity zone, (not at the top, as is presently done), to place the fluids farther from the surface.
2. Whenever possible, in completing storage wells, stereophotographs should be taken of the high transmissivity zone in order to determine distribution and size of the cavities and the amount of vertical connection, if any. Data obtained from the photographs will throw light on the presence or absence of fractures and small-scale faults in the area, which could not otherwise be detected. Stereophotographs will also provide a permanent, non-interpretive visual record of the well.
3. Use of the Cedar Keys and Upper Cretaceous cavity zones along the highly populated east coast of Florida for injection of industrial waste would be acceptable. Being deeper than the Eocene, these zones would be even less likely to ascend to shallower depths.

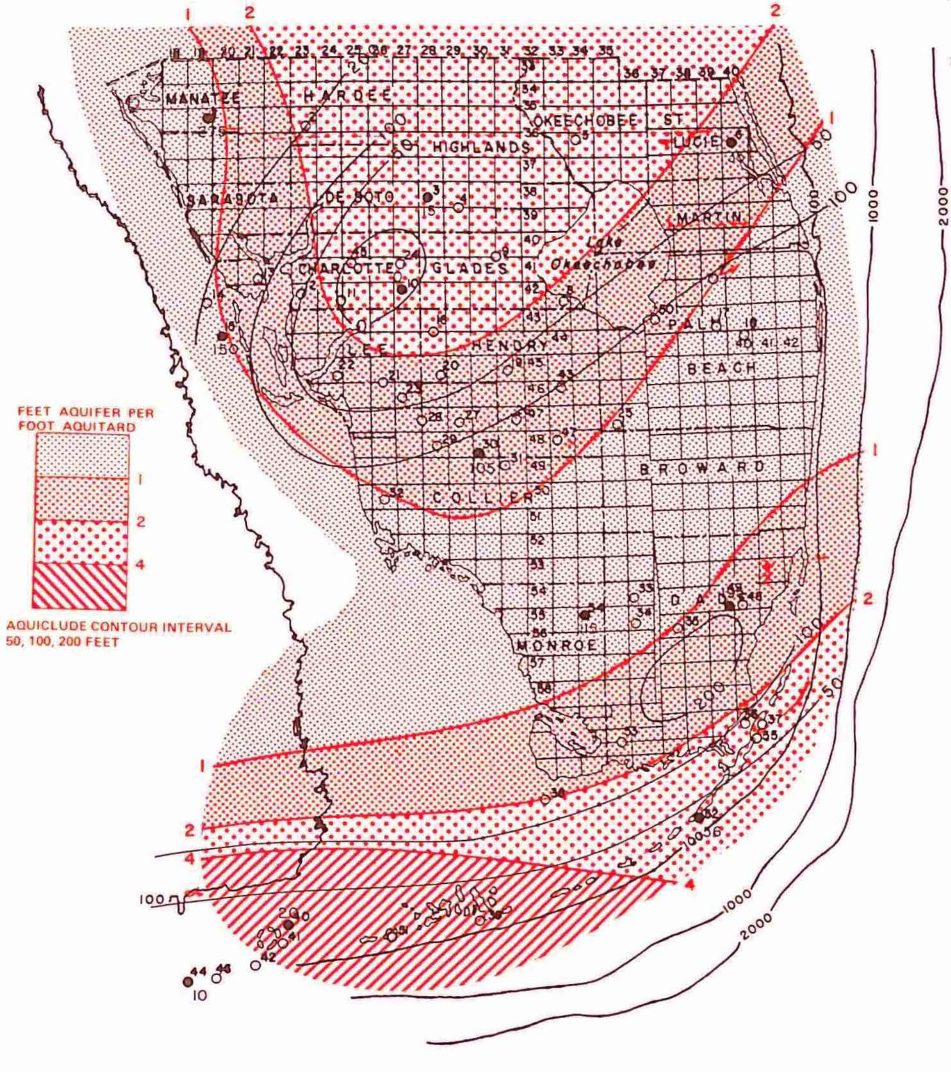


Figure 41 Map showing ratio of feet of aquifer per foot of aquitard and thickness of aquiclude in Unit Eo-3.

Figure 42 Map showing ratio of feet of aquifer per foot of aquitard and thickness of aquiclude in Unit Eo-2.

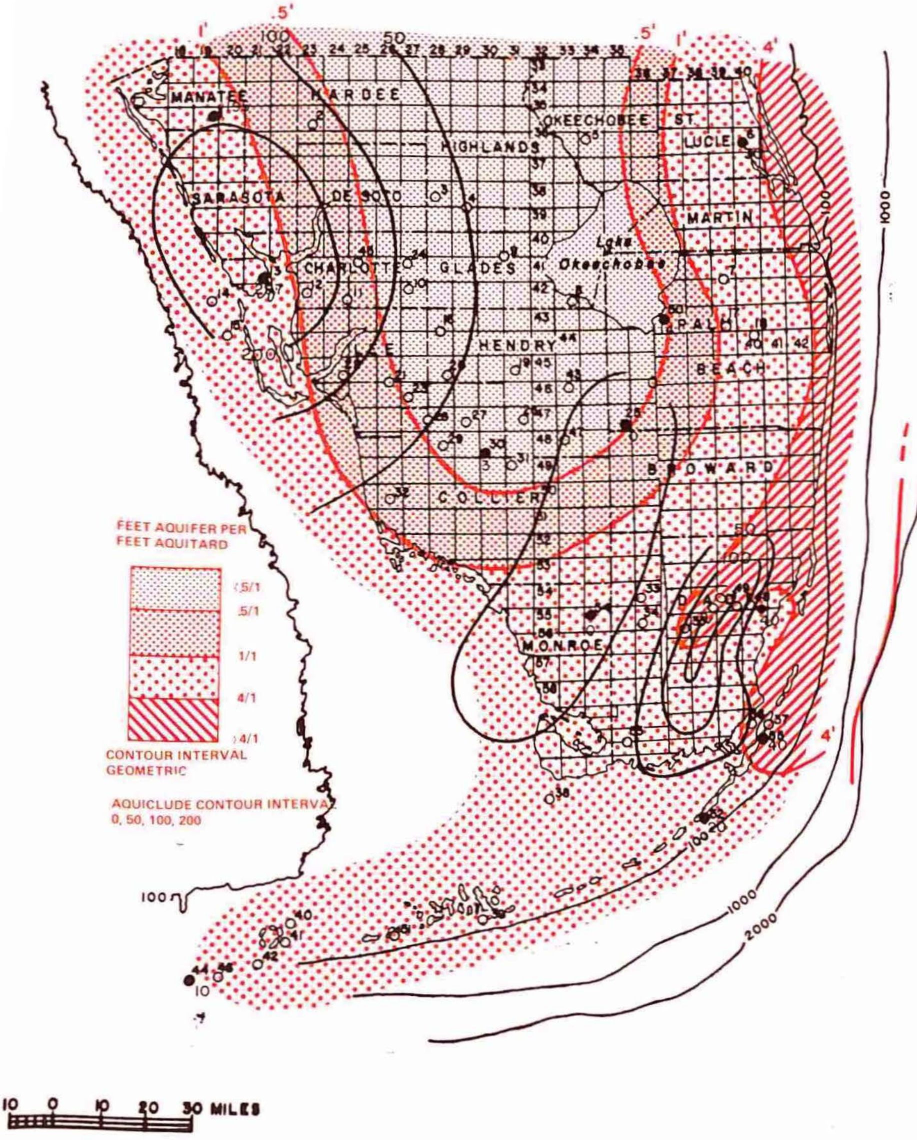


Figure 43 Map showing ratio of feet of aquifer per foot of aquitard and thickness of aquiclude in Unit Eo-1.

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APPENDICES

APPENDIX 1 ELECTRON SCANNING MICROPHOTOGRAPHS OF TYPICAL CARBONATE LITHOLOGIES

Figure 44 Scanning Electron Microphotograph of Skeletal limestone from Unit Eo-2, 100% coarse grained (depth 2435 - 50 ft.), Gulf-Cal. Block 46 (Well 46) Monroe County (X100).

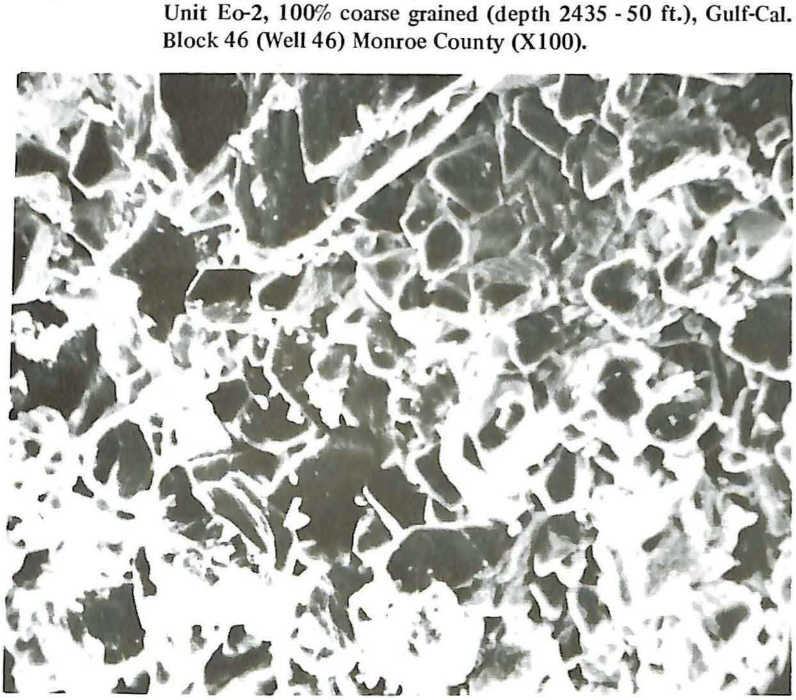

Figure 45 Same enlarged X2100 to show calcite crystals.

Figure 46 Scanning Electron Microphotograph of Skeletal limestone from Tampa Stage (depth 1160 - 70 ft.), Co stal No. 1 State (Well 52) Monroe County (X100).

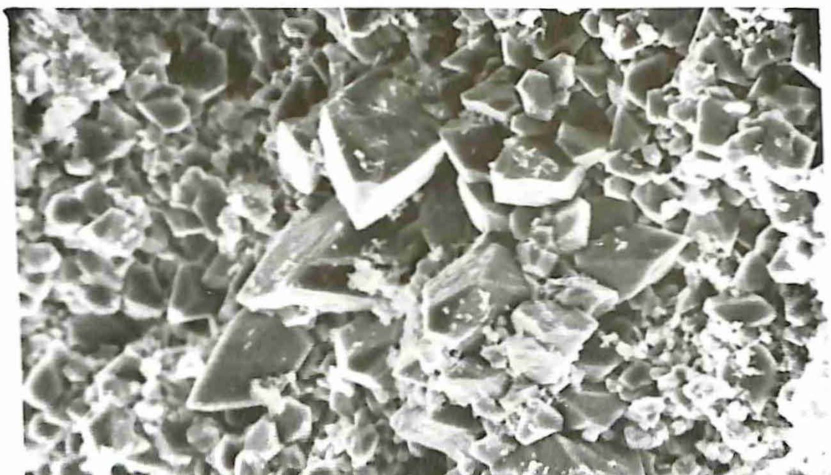

Figure 47 Same enlarged X1500 to show calcite crystals.

Figure 48 Scanning Electron Microphotograph of micritic limestone from Unit Eo-2 (depth 2650 - 60), Peninula No. 1 Cory (Well 54) Monroe County (X100).

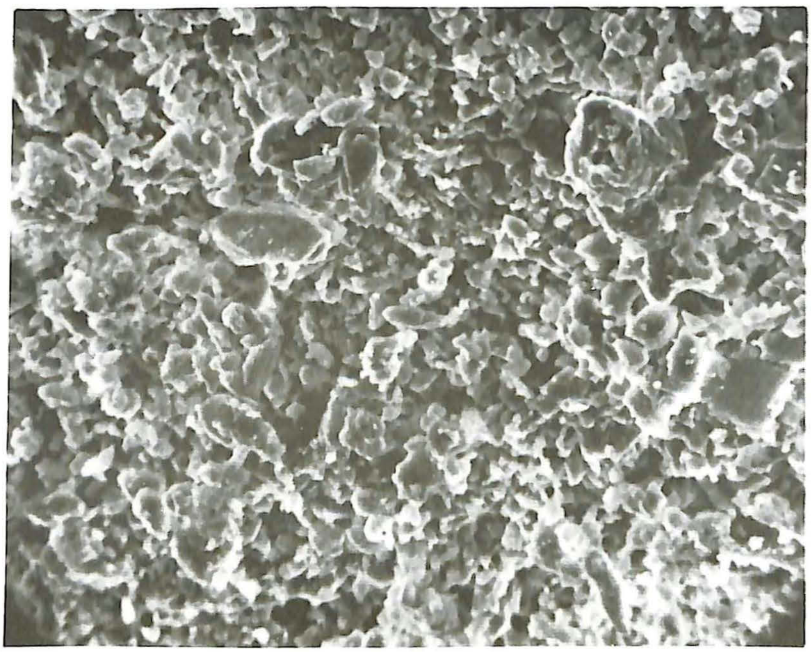

Figure 49 Same enlarged X2000 to show calcite crystals.

Figure 50 Scanning Electron Microphotograph of lithographic dolostone from Unit Eo-3 (depth 3540 - 50 ft.), Coastal No. 1 State (Well 52) Monroe County (X100).

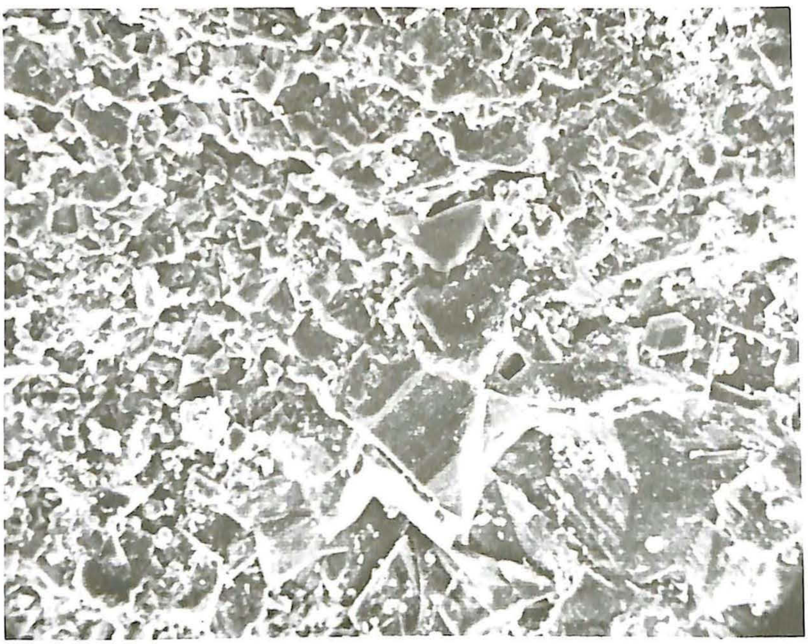

Figure 51 Same enlarged X1500 to show dolomite crystals.

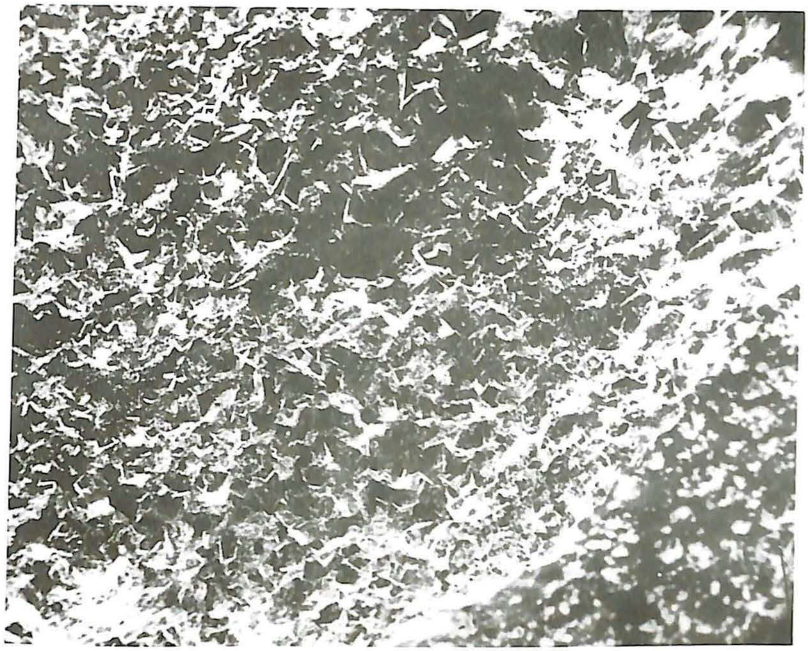

Figure 52 Scanning Electron Microphotograph of dolostone, microcrystalline, euhedral from Unit Eo-1 (depth 1470 - 80 ft.), Coastal No. 1 State (Well 52) Monroe County (X100).

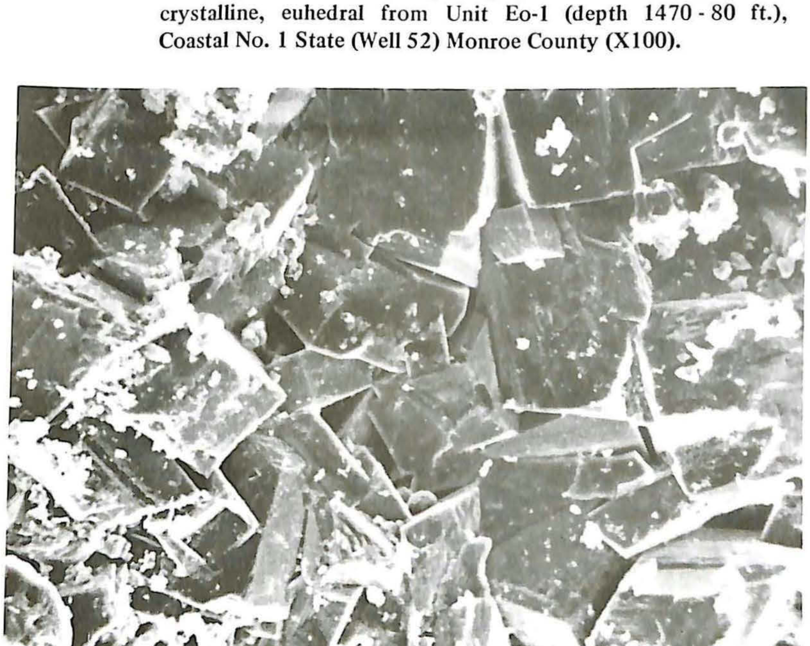

Figure 53 Same enlarged X1000 to show faces of dolomite crystals.

Figure 54 Scanning Electron Microphotograph of dolomite, fine crystalline, euhedral, Tampa Stage (depth 1035 ft.), Coastal No. 1 State Monroe County (X100).

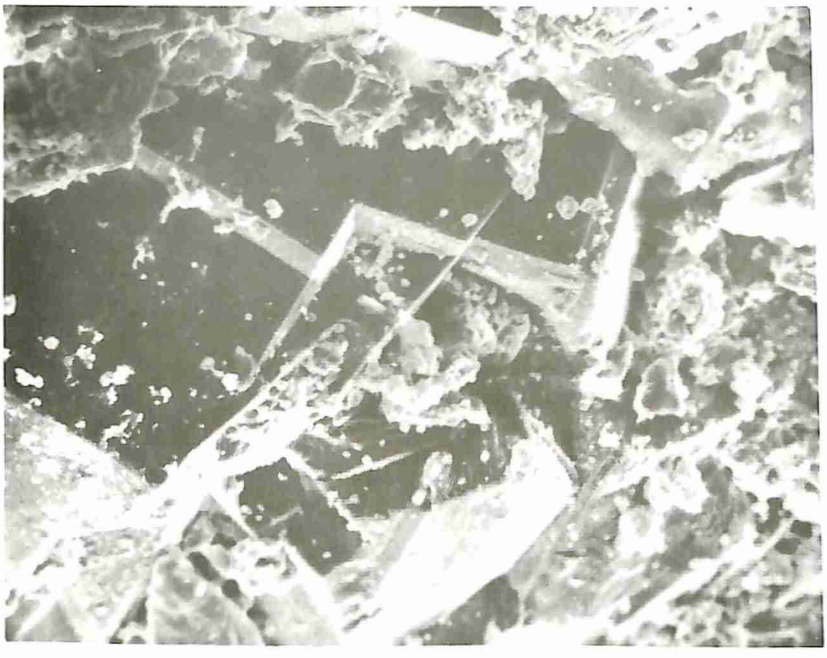

Figure 55 Same enlarged X1000 to show faces of dolomite crystals.

Figure 56 Scanning Electron Microphotograph of dolomite, medium crystal sucrosic, euhedral, 20% vugs and intragranular, porosity, Eo-3 (depth 3440 - 3500 ft.), Mobil No. 1 Babcock Ranch (Well 10), Charlotte County (X100).

Figure 57 Same enlarged X530 to show faces of dolomite crystals.

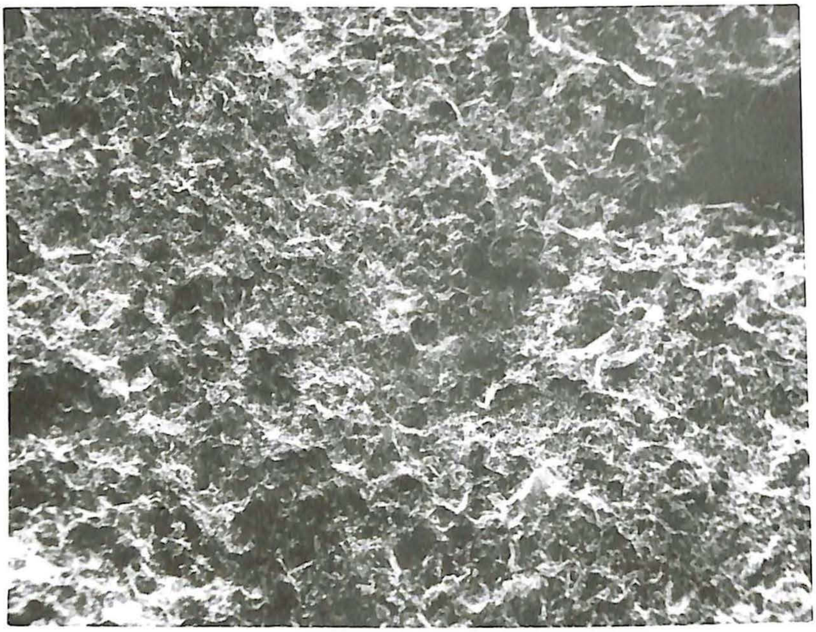

Figure 58 Scanning Electron Microphotograph of dolomite, very finely crystalline, anhedral, Upper Cretaceous, bank dolomite (depth 5210 - 20 ft.) Gulf-Cal. Block 46 (Well 46), Monroe County (X100).

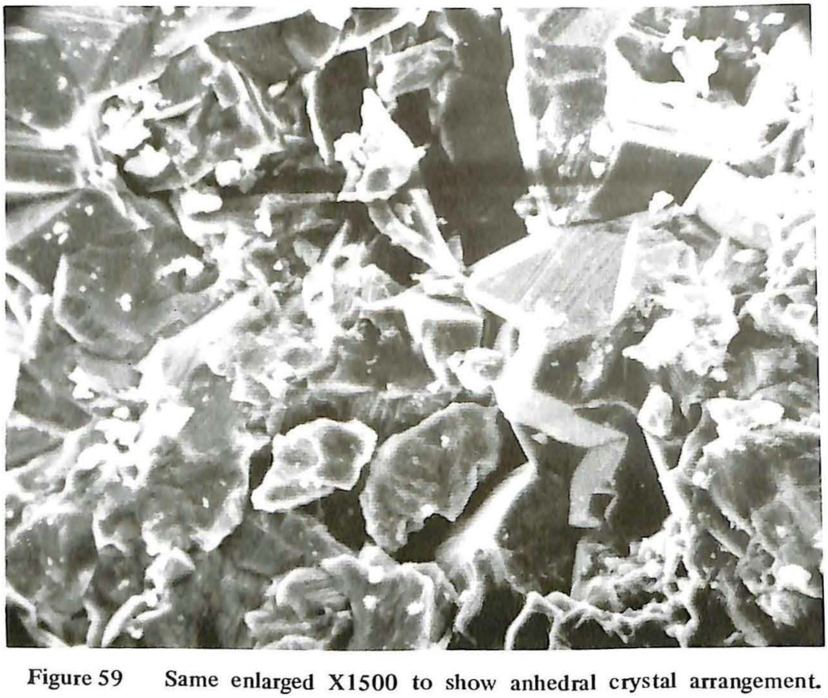

Figure 59 Same enlarged X1500 to show anhedral crystal arrangement.

APPENDIX 2 DESCRIPTION OF CAVITIES IN SUN 32-2 RED CATTLE STEREOPHOTOGRAPHS

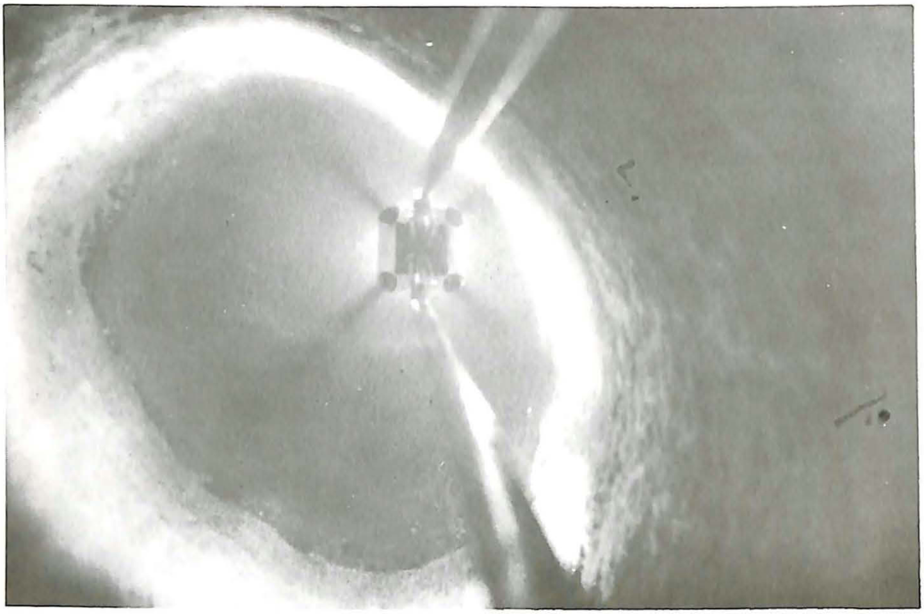

Figure 60 Photograph of 2230 foot level in Sun 32-2 Red Cattle.

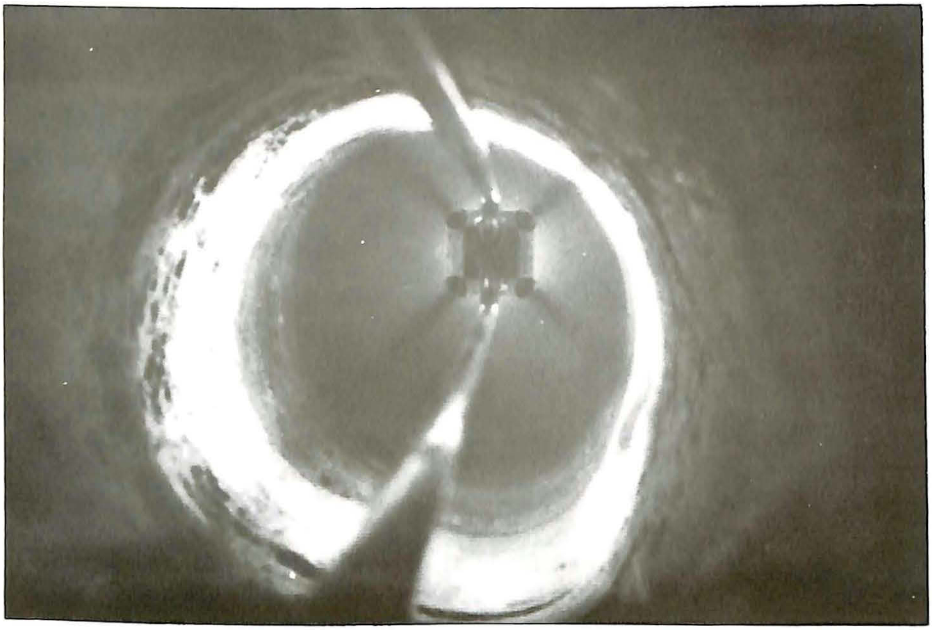

Figure 61 Photograph of 2258 foot level in Sun 32-2 Red Cattle.

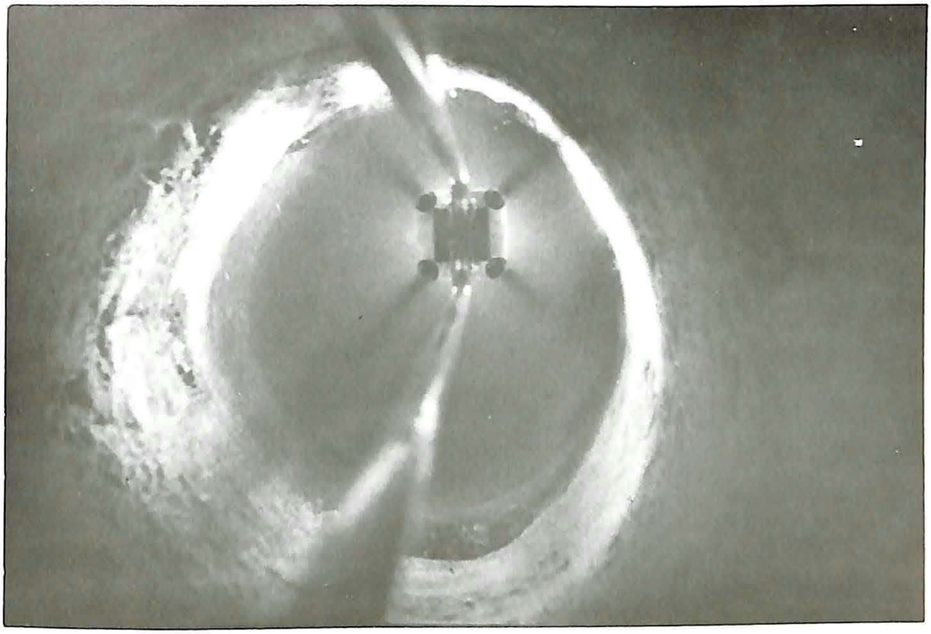

Figure 62 Photograph of 2272 foot level in Sun 32-2 Red Cattle.

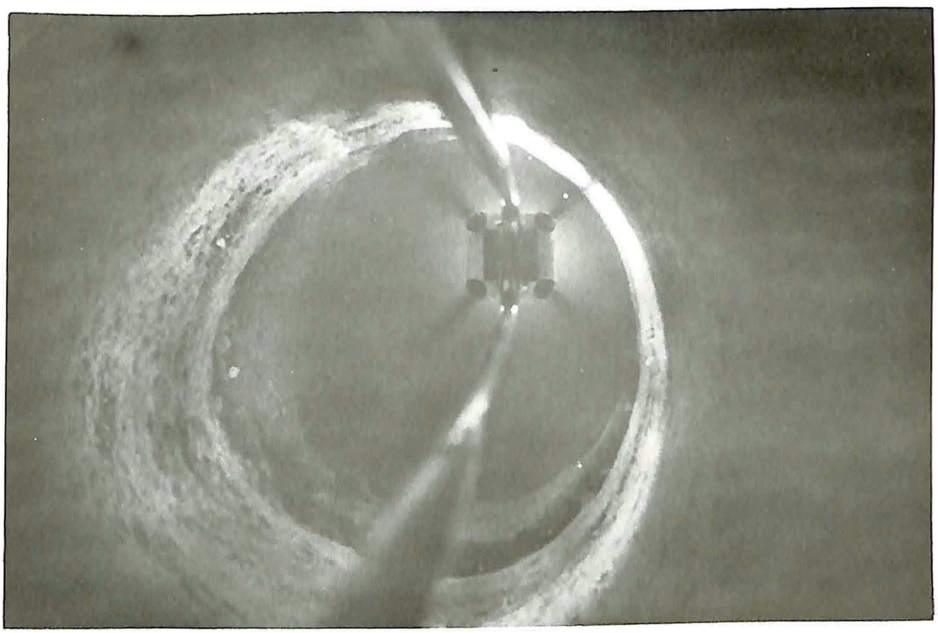

Figure 63 Photograph of 2308 foot level in Sun 32-2 Red Cattle.

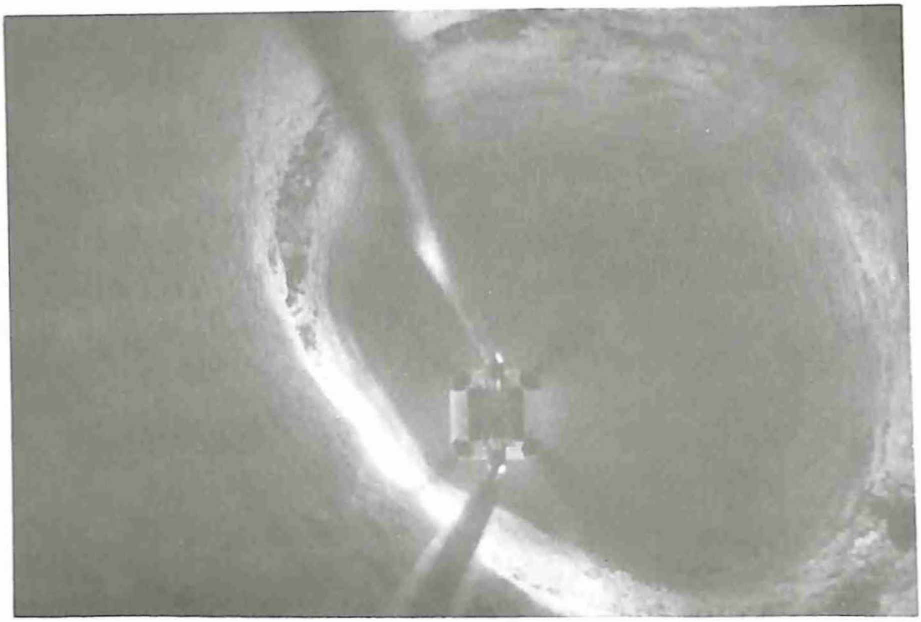

Figure 64 Photograph of 2376 foot level in Sun 32-2 Red Cattle.

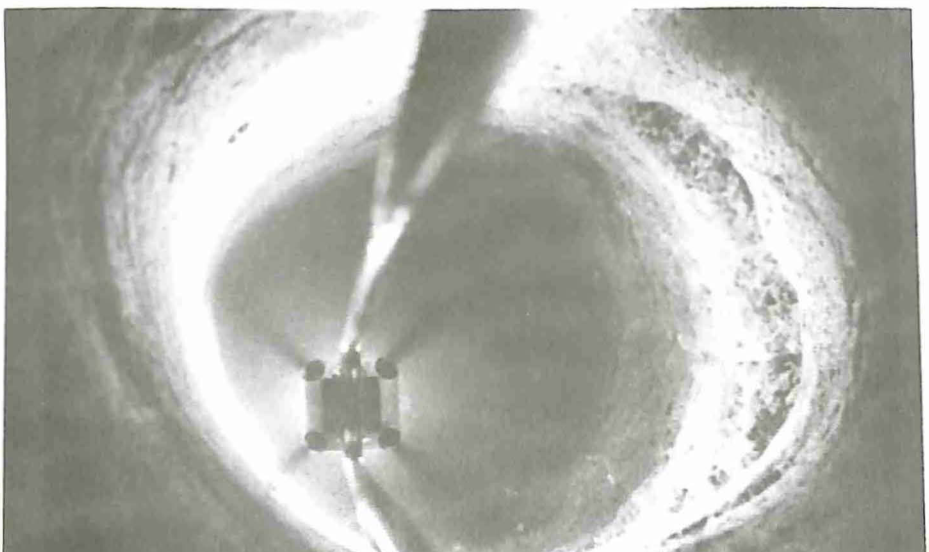

Figure 65 Photograph of 2436 foot level in Sun 32-2 Red Cattle.

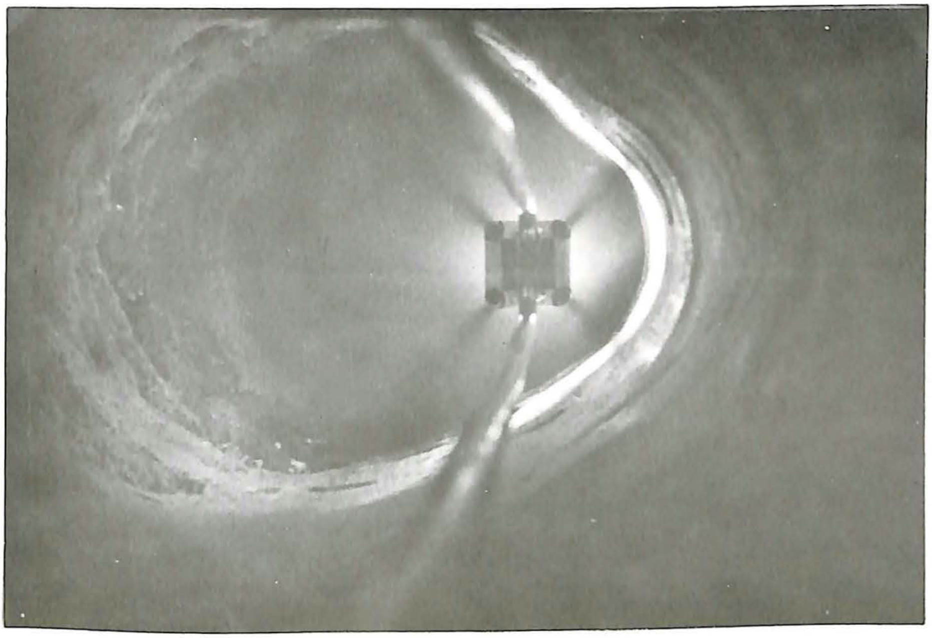

Figure 66 Photograph of 2496 foot level in Sun 32-2 Red Cattle.

APPENDIX 2

Description of Cavities in Sun 32 - 2 Red Cattle stereo-photographs

SIZE CLASSIFICATION FOR USE WITH THIS DESCRIPTION

vug	Largest dimension 3" or less, round unless otherwise specified
cavity	Largest dimension less than 2 feet, shape variable, usually discoid more than 3" high
cavern	Smallest dimension more than 2 feet

SHAPE CLASSIFICATION

tunnel	2 cavities, essentially round, where are so oriented that they probably extend across hole
pancake cavities	A stack of flat cavities, usually larger than full hole size

APPENDIX

Depth	Shape of Hole	Description
1343	round	murky
1344	round	murky
1346	round	murky
1350	round	enlarged open hole below casing, murky
1352		murky
1354	oval	no visible porosity, murky
1356	oval	murky
1358	oval	appears to have two small vugs a fraction of an inch in diameter, murky
1360	oval	no visible porosity, murky
1362	oval	no visible porosity, murky
1364	oval	no visible porosity, murky
1366	2 lobe	hole shape intergrading between above & below, murky
1368	2 lobe	smooth, murky
1370	2 lobe	smooth, murky
1372	2 lobe	smooth, murky (2 poss. ½" vugs)
1374	2 lobe	smooth, murky
1378	2 lobe	smooth, murky
1380	3 lobe	murky
1400	3 lobe	6" cavity (at least ½ hole)
1600	oval	took marks
1800	oval	probably becoming dolomitic, with irregularities in smooth wall looking like small washouts.
1900	oval	6" ¼ hole cavity at bottom?, murky
2000	oval	large 6" cavities, labyrinthine, occupies lower ½ of hole, also numerous vugs

Depth	Shape of Hole	Description
2100	egg	tool marks, 2 bands of black (peat?)
2200	egg	no visible porosity
2202	egg	no visible porosity
2204	egg	2" round vugs
2206	egg	tool marks
2208	egg	tool marks
2210	4 lobe	2 1" bands (peat ?)
2212	4 lobe	2 1" bands (peat ?)
2214	4 lobe	full hole cavity 2 - 3" high
2216	4 lobe	8 irregular shaped vugs 2 - 4" max. dia.
2218	4 lobe	20 vugs, most in a closely packed almost labyrinthine system, leading into large cavity, 1/3 hole, 8" high
2220	4 lobe	5 ½" vugs in smooth wall
2222	oval	poss 1 x 1/2" vug
2224	oval	tool marked wall w/1 x 1" vug
2226	oval	tool marks, banded
2228	oval	tool marks, banded
2230 (Fig. 60)	oval	5 4" vugs, 2 8" cavities; at bottom, 8" full hole cavity
2232	oval	4" ½ hole cavity, one large 6" cavity has "ledge" hanging out into hole about 2"
2234	5 lobe	5" cavity, banded
2236	5 lobe	4 3 x 3" vugs, otherwise non-porous; banded
2238	egg	dense, no visible porosity
2240	egg	dense, no visible porosity
2242	egg	dense, no visible porosity

Depth	Shape of Hole	Description
2244	egg	dense, no visible porosity
2246	2 lobe	milled-out ledge, cavity 8 x 16", dozens 1-2" vugs, banded
2250	2 lobe	dense, banded
2252	2 lobe	1 12 x 4" cavity across from 8 x 8" (tunnel ?) 7 2 x 2" vugs, banded
2256	2 lobe	3 4 x 8" cavities, banded
2258 (Fig. 61)	2 lobe	1 10 x 4", 2 6 x 6" cavities; 5 3 x 3" vugs; several cavities seem to be part of a labyrinthine system
2262	2 lobe	1 8 x 8" tunnel, 3 stack 4" pancake, ¼, ½ & full hole; probably labyrinthine numerous 2 x 5" cavities
2264	2 lobe	1 3/4 hole 3" cavity; r 1 x 3" vugs; 2 diagonal 1 x 6" cavities; 1 8 x 8" tunnel; banded
2268	round	2 1 x 12", 1 1 x 8", 2 1 x 4" cavities; 1 vertical cavity 2 x 8" intersecting a 1 x 12" cavity
2270	round	4 2 x 2", 1 1 x 3" vugs, banded
2272 (Fig. 62)	4 lobe	labyrinthine vug zone on ½ wall, 12" thick; 2 10" tunnels apparently cross in hole, numerous vugs
2274	round	12" cavity zone w/3 x 10" irregular roofed cavity; 1 3 x 3" vugs probably tunnel back and re-enter hole; rest of hole no visible porosity
2276	round	10 1" vugs, 1 3 x 5" cavity, bubbles
2278	round	5 x 10" cavity; triangular cavity 5"; 4 1 x 3" vugs; bubbles in water
2280	round	15 1" vugs in 2 zones; triangular cavity in upper part of hole as above
2282	round	bubbles
2284	oval	no visible porosity, reduced hole diameter due to drilling, banded, bubbles in water
2286	oval	4 2 x 6" cavities, tool marks, bubbles in water

Depth	Shape of Hole	Description
2288	oval	2 2 x 4" cavities, took marks, cavity 4 x 4", irregular vertical solution channel
2290	oval	same vertical channel as above, 2" horizontal vug band, bubbles in water
2292	oval	occasional irregular vugs
2294	oval	occasional vugs
2294	oval	occasional small vugs, banded
2298	oval	1 diagonal cavity 1 x 8"; 1 vertical cavity 1 x 6", banded
2300	oval	1 10 x 10" cavity with roof slab loose; floor covered with cuttings and stick! 3 2 x 2" vugs
2302	oval	sucrosic zone
2304	oval	3 1 x 4" cavities, banded
2306	oval	3" zone w/3 1 x 4" cavities, banded
2308 (Fig. 63)	oval	2 stack pancake, 1 full hole 1 3/4 occupied hole; 3 x 3" vugs, occasional small vugs
2312	oval	2 cavity zones, 6" thick; 2 1 x 6" 1 4 x 4" cavities, 2 3 x 3" vugs, 14" cavity half hole w/roof debris overhanging hole; 1 8 x 8" tunnel
2314	oval	1 8 x 8" cavity, 4 3 x 3" vugs
2322	oval	2 cavity zones 6" thick 6" apart labyrinthine, w/max. size cavities 4 x 10" many 3 x 3" vugs, irregular horizontal cavities; bubbles in water
2330	oval	1 3" vug, banded
2332	oval	2 labyrinthine cavity zones, both ½ hole; 3 3 x 3" vugs, 1 4 x 4" cavity, 1 6 x 6" cavity, 3 4 x 4" cavities
2336	oval	3 6 x 6", 3 4 x 4" cavities in 12" zone
2338	oval	more than 20 3 x 3" vugs
2344	3 lobe	1 6 x 6" cavity, 1 3 x 3" vug

Depth	Shape of Hole	Description
2346	3 lobe	8" cavity zone w/t 4 x 4" cavities, 6 3 x 3" vugs in rows, banded
2348	3 lobe	banded carbonate w/cavity zone in one of the bancs w/4 x 10" cavities
2350	3 lobe	continuation of banding w/2 more cavity zones separated by a band
2352	3 lobe	1 2 x 6", 1 2 x 4" cavity, banded
2354	3 lobe	4" band of ½" vugs or sucrosic porosity
2356	3 lobe	8 2 x 2" vugs, tool marks
2362	3 lobe	cavity zone 12" thick; 1 4" full hole cavity 3 4 x 4" cavities
2364	3 lobe	3" soft zone small vugs or sucrosic porosity; mottled dark & light at bottom picture banded, mottled
2366	3 lobe	1 4 x 4" cavity, all else dense, banded
2368	3 lobe	no visible porosity with soft (sucrosic) zone; milled out ledge
2370	3 lobe	no visible porosity
2372	3 lobe	1 3 x 5" cavity, 2 3 x 3" vugs
2374	3 lobe	1 3 x 6" full hole cavity
2376 (Fig. 64)	3 lobe	1 6 x 15" tunnel, 1 8 x 8" tunnel & 6 x 6" cavity near bottom picture
2382	3 lobe	1 4 x 8", 1 4 x 4" cavity, occasional vugs
2384	3 lobe	1 tunnel 10 x 10" becoming 6 x 6"; 1 5 x 5" cavity
2390	3 lobe	3 stack pancake ½ hole, 6", 4", 4"
2394	3 lobe	1 3 x 6" cavity; 2 3 x 3", 2 2 x 2" vugs
2396	3 lobe	murky, numerous vugs
2398	3 lobe	occasional vugs
2400	3 lobe	no visible porosity, took marks

Depth	Shape of Hole	Description
2402	oval	no visible porosity, tool marks
2412	oval	1 ½ hole cavity 4"
2414	oval	no visible porosity
2416	oval	2 3" vugs
2418	oval	1 8 x 8" cavity, 1 2 x 6" cavity, 1 vug
2420	egg	no visible porosity
2422	egg	½ hole 12" cavity with vertical solution channel 2 x 10", several vugs, 1 3 x 6" cavity
2428	egg	1 3 x 3" vug; 1 ½ hole 4" cavity enchelon with 4 x 10" cavity
2432	egg	1 6 x 6" tunnel; 18" zone vugs, 1 vertical solution channel
2434	oval	1 8 x 8" cavity; 1 half hole 6" cavity, scattered vugs
2436 (Fig. 65)	oval	1 half hole 8" cavity, 14 x 14" tunnel, scattered vugs
2438	oval	1 3 x 3", 3 2 x 2" vugs
2440	oval	1 full hole 12" cavity at bottom picture vertical and diagonal solution channel 3" zone of vugs
2446	oval	(? ?) 2 stack pancake ½ hole at top picture; 12" cavity zone with labyrinthine horizontal 6 - 10" cavities, fully occupying the hole
2448	oval	1 8 x 8" jagged cavity at top picture, 1 6 x 10" cavity near bottom picture, 1 soft zone, 4 x 8", small vugs (? ?)
2452	oval	2 4 x 8" cavities, en echelon at top picture, 1 4 x 8" cavity; 1 2 x 2" vug, 3 2 x 4" cavities; 1 4 x 4" cavity
2454	oval	2 3 x 4" cavities; 3 3 x 3" vugs
2456	oval	labyrinthine cavity system fully occupying the hole at bottom of the picture, details obscured, appears to be overlapping 4 x 10" cavities

Depth	Shape of Hole	Description
2458	oval	labyrinthine overlapping cavities in 2 zones 12" thick; cavities varying between 3 x 6" & 4 x 10"
2462	2 lobe	3 cavity zones: upper 12" thick with 2 6 x 12" cavities - several smaller; 6" dense; middle 1 2 x 2" vug, 1 6 x 12" cavity, cavity en echelon with 4 x 8" cavity 4" dense zone; lower full hole cavity 8" high
2468	oval	1 12 x 16" cavity at top picture, also 3 3 x 4" cavities
2470	oval	1 2 x 4", 1 3 x 6" cavity, several vugs
2472	oval	3 3 x 8", 2 3 x 4" cavities, banded
2474	oval	1 ½ hole 6" cavity
2476	oval	tool marks, milled ledge, sucrosic zone
2478	oval	1 full hole 4", 1 3 x 4" cavity, scattered vugs
2482	oval	1 full hole cavity at limit of visibility at bottom of picture, probably 4" thick; otherwise non-porous
2484	oval	1 full hole cavity 6" high
2488	2 lobe	4 2 x 2" vugs; 1 4 x 10" cavity, scattered vugs
2490	2 lobe	1 full hole cavity 6" thick
2492	2 lobe	1 4 x 12", 4 4 x 4" cavities; 1 4" tunnel; 2 vertical cavities 2 x 8", 2 4 x 8" cavities; 1 half hole cavity 6" high at limit of visibility at bottom of picture
2496 (Fig. 66)	2 lobe	1 6 x 6", 10 3 x 3" vugs, 3 stack pancake 12" thick ¾ hole
2498	2 lobe	4" tunnel, 1 4 x 8" cavity; banded rock; full hole 6" cavity at bottom picture, banded
2500	2 lobe	1 half hole 6" cavity; 1 full hole 8" cavity, numerous vugs
2502	2 lobe	1 4 x 12" cavity, several vugs, banded
2504	3 lobe	dense, non-porous
2510	3 lobe	dense, non-porous

Depth	Shape of Hole	Description
2512	3 lobe	1 3 x 6" diagonal cavity; ½ picture murky
2514	3 lobe	1 3" (at least) half hole cavity; ½ hole not visible
2516	3 lobe	no visible porosity
2518	3 lobe	no visible porosity
2520	3 lobe	1 3 x 6", 1 4 x ¼ hole (at least) cavities otherwise no visible porosity
2522	3 lobe	1 6" half hole (at least) cavity, occasional vugs
2530 - 2576	–	Nothing visible, open cavern
2578	–	open cavern; bent drill pipe visible
2580	–	open cavern; bent drill pipe visible
2602	–	overlapping ledges
2604	–	overlapping ledges
2610	–	
2616	round	1 8 x 12" cavity; zone of cavities 2 feet thick with numberous cavities from 3 x 3" to 3 x 6"

APPENDIX 3 LIST OF WELLS ON MAPS

APPENDIX 3

TABLE OF WELLS

Well No.	Bureau of Geology Accession No.	Operator	Lease	County	Sec.	Twp.	Rge.
1.	W-3612	Mobil	1 Schroeder	Manatee	11	35	19
2.	W-1655	Humble	1 Keene	Hardee	23	35	23
3.	W-3578	Continental	1 Carlton	Highlands	20	38	28
4.	W-966	Humble	1 Carlton	Highlands	34	38	29
5.	W-3739	Amerada	1 Swenson	Okeechobee	5	36	34
6.	W-4323	Amerada	2 Cowles Magazine	St. Lucie	19	36	40
7.	W-3671	Amerada	1 Southern States	Palm Beach	34	41	39
8.	W-2912	Coastal	1 Tiedtka	Glades	25	42	33
9.	W-4750	Amerada	1 Lykes	Glades	1	41	30
10.	W-8079	Mobil	1 Babcock Ranch	Charlotte	9	42	27
11.	W-6674	Gulf	1 Stevens	Charlotte	24	42	24
12.	W-7007	Humble	1 Loundes-Treadwell	Charlotte	17	42	23
13.	W-3214	Gulf	1 Vanderbilt	Charlotte	35	41	21
14.	W-8139	Mobil	1 State (224-B)	Charlotte	Offshore		
15.	W-5785	California	2 State (224-B)	Lee	Offshore		
16.	W-7660	So. Triangle	2 Lawless	Hendry	34	43	28
17.	W-8322	Amerada	1 Conn. Sugar	Palm Beach	35	43	40
18.	W-1471	Humble	1 Tuscan	Palm Beach	35	43	40
19.	W-7703	Sun	1-A Alico	Hendry	27	45	31
20.	W-3319	Commonwealth	3 Red Cattle	Hendry	25	45	28
21.	W-2979	Gulf	1 CNS	Lee	27	45	26
22.	W-3073	Humble	1 Kirchoff	Lee	23	45	24
23.	W-4839	Humble	1 CNS	Lee	16	46	27
24.	W-10717	Exchange	1 Payson	Charlotte	7	41	27
25.	W-4661	Humble	1 State(1004)	Palm Beach	2	48	35
26.	W-2631	Humble	B-1 Collier Corp.	Hendry	14	47	31
27.	W-3579	Humble	1 Curry	Collier	8	47	29

TABLE OF WELLS (Continued)

Well No.	Bureau of Geology Accession No.	Operator	Lease	County	Sec.	Twp.	Rge.
28.	W-2103	Humble	E-1 GCRC	Collier	19	47	28
29.	W-	Gulf American	1 East Gate	Collier	16	48	28
30.	W-10252	US Gyp	1 Sunniland	Collier	24	48	29
	W-2142	Humble	16 GCRC		14	48	29
31.	W-5558	Humble	1 Miles Collier	Collier	18	49	31
32.	W-2420	Humble	1 Collier Corp.	Collier	27	50	26
33.	W-5010	Commonwealth	1 State (1005)	Dade	11	54	35
34.	W-889	Humble	IIF	Dade	30	55	36
35.	W-2038	Coastal	1 State (340-A)	Dade	25	55	37
36.	W-902	Republic	1 State	Monroe	29	50	40
37.	W-30ll	Sinclair	1 Williams	Monroe	29	59	40
38.	W-3510	Gulf	1 State (826-G)	Monroe	Offshore		
39.	W-972	Gulf	1 State (373)	Monroe	2	68	29
40.	W-5094	Gulf	1 State (826-Y)	Monroe	Offshore		
41.	W-5970	California	3 State (1011)	Monroe	Offshore		
42.	W-5327	Gulf-California	OCS Blk 28	Monroe	Offshore		
43.	W-10625	Exchange	1 Fla. Land	Hendry	17	46	33
44.	W-3174	Gulf-California	OCS Blk 44	Monroe	Offshore		
45.	W-10862	Exchange-Shell	1 State (2448)	Charlotte	9	41	25
46.	W-6148	Gulf-California	OCS Blk 46	Monroe	Offshore		
47.	W-10747	Mobil	1 Seminole	Hendry	8	48	33
48.	W-10245	Peninsula Util.	1 Kendall	Dade	32	54	40
49.	W-11321	Peninsula Util	1 Kendal Lakes	Dade	34	54	39
50.	W-7500	Sugar Cane Coop	1 Belle Glade	Palm Beach	28	36	37
51.	W-5152	California	1 State (1011)	Monroe	1	67	29
52.	W-1976	Coastal	1 State (363)	Monroe	32	62	38

TABLE OF WELLS (Continued)

Well No.	Bureau of Geology Accession No.	Operator	Lease	County	Sec.	Twp.	Rge.
53.	W-1115	Gulf	1 Model Land	Dade	8	60	35
54.	W-445	Peninsula Oil	1 Cory	Monroe	6	55	34
55.	W-2130	Coastal	1 Williams	Monroe	25	59	40
56.	W-23	Water Well		Manatee	15	34	17
57.	W-2732	Water Well		Hardee	3	33	24
58.	W-4489	Water Well		Sarasota	7	36	18
59.	W-4947	Water Well		Sarasota	17	37	18
60.	W-106	Water Well		Sarasota	34	36	19
61.	W-2595	Water Well		Manatee	34	36	21
62.	W-894	Water Well		Highlands	28	34	29
63.	W-1464	Water Well		Highlands	2	36	29
64.	W-6192	Water Well		DeSoto	30	37	26
65.	W-50	Water Well		Okeechobee	16	37	35
66.	W-2860	Water Well		Martin	31	38	38
67.	W-2861	Water Well		Martin	9	38	40
68.	W-	Shell	22-1 Punta Gorda Isles	DeSoto	22	39	27
69.	W-F1417	Humble	Core Test	Charlotte	6	41	26
70.	W-F1411	Humble	Core Test	Charlotte	22	42	26
71.	W-10600	Humble	8-2 Lehigh	Lee	8	45	27
72.	W-5010	Comm-Coastal	1 State	Dade	11	54	35
73.	W-7362	Water Well		Monroe	23	61	39
74.	W-11571	Fla. Power Light	Turkey Point	Dade	28	58	40
75.	W-6929	Sun	32-2 Red Cattle	Hendry	32	45	29
76.	W-3441	Humble	1 CNS	Hendry	5	45	29
77.	W-1916	Humble	14 GCRC	Collier	20	48	30
78.	W-2142	Humble	16 GCRC	Collier	14	48	29
79.	W-5713	California	2 State (1011)	Monroe	Offshore		

GLOSSARY

1. Calcarenite. A limestone with over 50 percent sand-sized grains.

2. Calcilutite. Micro-structured limestone with less than 50 percent sand-sized grains; usually a consolidated lime mud. Occasionally this rock may be a completely recrystallized calcarenitic limestone in which all original texture was destroyed, only "ghosts" or color differences remaining to indicate original fossil fragments.

3. Euhedral. Refers to dolomite crystal structure in which individual crystals are separate and can be seen quite plainly. May exhibit sucrosic texture.

4. Anhedral. Refers to dolomite crystal structure in which individual crystals are interlocked; and never exhibit sucrosic texture.

5. Grainstone. A limestone with grains supported; lacks mud (micrite) interstitial filling. Greater than 70% grains; may be completely cemented.

6. Packstone. Same as grainstone but contains mud (micrite).

7. Micrite. A limestone of less than .06mm grain size.

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DEPARTMENT OF NATURAL RESOURCES
BUREAU OF GEOLOGY

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